Appendix I: Climate impacts and adaptation actions for Lewis's woodpecker

The Washington-British Columbia Transboundary Climate-Connectivity Project engaged science-management partnerships to identify potential climate impacts on wildlife habitat connectivity and adaptation actions for addressing these impacts in the transboundary region of Washington and British Columbia.[i] Project partners focused their assessment on a suite of case study species, vegetation systems, and regions chosen for their shared priority status among project partners, representation of diverse habitat types and climate sensitivities, and data availability. This appendix describes potential climate impacts and adaptation actions identified for the Lewis's woodpecker (*Melanerpes lewis*).

Figure I.1. Lewis's woodpecker.

Lewis's woodpecker is patchily distributed throughout the transboundary region during the spring-summer breeding season. Due to its excellent dispersal abilities, Lewis's woodpecker likely experiences few barriers to movement within the transboundary region (Appendix I.1). However, Lewis' woodpecker habitat connectivity may be affected by threats to its core habitat of ponderosa pine forest, which faces loss and degradation due to insect pests, fire, and human activities.[2]

Future climate change may present additional challenges and needs for Lewis's woodpecker habitat connectivity.[3-4] First, climate change may impact Lewis's woodpecker core habitat and dispersal habitat in ways that may make them more or less permeable to movement. Second, existing Lewis's woodpecker core habitat and dispersal habitat may be distributed on the landscape in ways that make them more or less able to accommodate climate-driven shifts in Lewis's woodpecker distributions. For such reasons, connectivity enhancement has become the most frequently recommended climate adaptation strategy for biodiversity conservation.[5] However, little work has been done to translate this broad strategy into specific, on-the-ground actions. Furthermore, to our knowledge, no previous work has identified specific climate impacts or adaptation responses for Lewis's woodpecker habitat connectivity. To address these needs, we describe here a novel effort to identify and address potential climate impacts on Lewis's woodpecker habitat connectivity in the transboundary region of Washington and British Columbia.

Potential climate impacts on habitat connectivity

To identify potential climate impacts on transboundary Lewis's woodpecker habitat connectivity, project partners created a conceptual model that identifies the key landscape features and processes expected to influence Lewis's woodpecker habitat connectivity, which of those are expected to be influenced by climate, and how (Appendix I.2). Simplifying complex ecological systems in such a way can make it easier to identify specific climate impacts and adaptation actions. For this reason, conceptual models have been promoted as useful adaptation tools, and have been applied in a variety of other systems.[6] The Lewis' woodpecker conceptual model was developed using peer-reviewed articles and reports, project participant expertise, and review by species experts. That said, the resulting model is intentionally

[i] This report is Appendix I of the Washington-British Columbia Transboundary Climate-Connectivity Project; for more information about the project's rationale, partners, methods, and results, see Krosby et al. (2016).[1]

simplified, and should not be interpreted to represent a comprehensive assessment of the full suite of landscape features and processes contributing to Lewis' woodpecker habitat connectivity.

Project participants used conceptual models in conjunction with models of projected future changes in relevant climate variables to identify potential impacts on Lewis's woodpecker connectivity. Because a key project goal was to increase practitioner partners' capacity to access, interpret, and apply existing climate and connectivity models to their decision-making, project partners relied on a few primary datasets that are freely available, span all or part of the transboundary region, and reflect the expertise of project science partners. These sources include habitat connectivity models produced by the Washington Connected Landscapes Project,[7,8] future climate projections from the Integrated Scenarios of the Pacific Northwest Environment[9] and the Pacific Climate Impacts Consortium's Regional Analysis Tool,[10] and models of projected range shifts produced as part of the Pacific Northwest Climate Change Vulnerability Assessment.[11]

Key impacts on transboundary Lewis's woodpecker habitat connectivity identified via this approach include changes in the size and location of climatically suitable Lewis's woodpecker habitat, changes in disturbance regimes, and changes in temperature and precipitation.

Changes in areas of climatic suitability

Climate change may impact Lewis's woodpecker habitat connectivity by changing the extent and location of areas of climatic suitability for Lewis's woodpecker; this may render some existing core habitat areas and dispersal habitat unsuitable for Lewis's woodpecker, and/or create new areas of suitability. Climatic niche models provide estimates of species' current and projected future areas of climatic suitability, and are available for the Lewis's woodpecker for the 2080s based on two CMIP3 Global Circulation Models (GCMs) (CGCM3.1(T47) and UKMO-HadCM3[ii]) under the A2 (high) carbon emissions scenario[iii] (Appendix I.3).

For both climate models, projections for the 2080s show a fairly substantial contraction of climatically suitable habitat, although the spatial distribution of the losses differs somewhat depending on the climate model used. For both climate models, suitability declines in the Okanagan Valley as well as to the east in the lower Monashee Mountains. Some areas of stability remain under both scenarios in the mid-elevations to the east and west of the Okanagan and on the east side of the Cascades. In addition, for both climate models, some higher elevation peaks in the Purcell and Rocky Mountains increase in climatic suitability.

Under the CGCM3.1(T47) scenario, there is greater loss of climatically suitable habitat to the east of the Okanagan Valley, while under the UKMO-HadCM3 scenario, there is greater loss on the west side of the Valley.

[ii] CGCM3.1(T47) and UKMO-HadCM3 are two different Global Circulation Models (GCMs) used to project future changes in climate. The UKMO-HadCM3 model projects a much hotter and drier summer, while the CGCM3.1(T47) projects greater precipitation increases in spring, summer and fall. For these reasons, the UKMO-HadCM3 could be considered a "hot-dry" future, while the CGCM3.1(T47) could be considered a "warm-wet" future within the Pacific Northwest.

[iii] Emissions scenarios were developed by climate modeling centers for use in modeling global and regional climate-related effects. A2 is a high, "business as usual" scenario in which emissions of greenhouse gases continue to rise until the end of the 21st century, and atmospheric CO_2 concentrations more than triple by 2100 relative to pre-industrial levels.

Changes in fire regime

Increasing temperatures are expected to extend fire seasons in the western United States and increase the percentage of area burned in some areas (Appendix I.6: Days with High Fire Risk).[12] The impacts of changes in fire regime to Lewis's woodpecker habitat connectivity will depend on fire return intervals, severity, size, location, and on the subsequent successional trajectories of vegetation. While moderate-intensity fires are generally beneficial to ponderosa forests (a preferred habitat type of Lewis's woodpecker), high intensity and widespread fires can be destructive.[13]

Changes in insect pests

Ponderosa pine forests provide important breeding habitat for Lewis's woodpecker. Mountain pine beetles can be highly destructive in pine forests if they reach epidemic levels. However, at endemic levels, these beetles help create snags that Lewis's woodpeckers use for nesting. In Washington State, probability of mountain pine beetle survival is projected to decline at lower elevations, but to increase at high elevations (Appendix I.5). Other pests that may impact Lewis's woodpecker include the spruce budworm and the western pine beetle. Defoliation from spruce budworm infestation during summer would likely have a negative impact on Lewis' woodpecker core habitat, while the effects of western pine beetle on yellow pine may improve habitat.

Changes in water availability

Riparian areas, particularly those with cottonwoods, provide important foraging grounds for Lewis's woodpecker. Snowmelt and spring precipitation (Appendix I.6: Spring (April 1st) Snowpack; Total Spring Precipitation) are both important for maintaining riparian forests. Riparian areas also require sufficient moisture to survive summer drought (Appendix I.6: Soil Moisture, July-September). Spring precipitation is projected to increase, which may benefit riparian forests, but spring and summer snow melt is projected to decrease. At the same time, summers are expected to become hotter and drier, which may stress riparian forests (Appendix I.6: Total Spring Precipitation; Potential Evapotranspiration, July-September; Dry Spell Duration; Spring (April 1st) Snowpack). Unfortunately, the scale of both mechanistic and climatic niche vegetation model projections is too coarse for assessment of fine-scale features like riparian vegetation.

Adaptation responses

After identifying potential climate impacts on Lewis's woodpecker habitat connectivity, project participants used conceptual models to identify which relevant landscape features or processes could be affected by management activities, and subsequently what actions could be taken to address projected climate impacts (Appendix I.2). Key adaptation actions identified by this approach fall under three main categories: those that address potential climate impacts on Lewis's woodpecker habitat connectivity, those that address novel habitat connectivity needs for promoting climate-induced shifts in distributions for Lewis's woodpecker, and those that identify spatial priorities for implementation.

Addressing climate impacts to Lewis's woodpecker connectivity

Actions to address the potential for climate change to affect habitat connectivity through widespread forest loss due to wildfire or epidemic outbreaks of insect pests include:

- Using prescribed burns and thinning to reduce the risk of catastrophic wildfires and pest outbreaks that could negatively impact Lewis's woodpecker core habitat and dispersal habitat. Consider engaging traditional ecological knowledge to help guide implementation, referencing tribal and First Nation forest and grazing practices to identify traditional strategies for managing fire risk and other potential climate impacts.

- Incorporating projections and observations of changes in the length of the snow season, evapotranspiration, soil moisture deficits, and the timing of precipitation to inform the timing of fire prevention techniques as conditions change, in order to maximize their safety and effectiveness.

Actions to address the potential for climate change to negatively impact core habitat areas and dispersal habitat in the transboundary region:

- Focusing habitat retention efforts on riparian habitats, which may become less suitable as climate warms. Lewis's woodpeckers frequently forage in riparian areas.
- Planning and managing corridors so that water resources, such as streams or wetlands, are available; these may become increasingly important as the climate changes, particularly in lowland dry valleys such as the Okanagan Valley.
- Retaining snags greater than 30 cm in diameter during forest harvest activities to provide nesting and foraging resources throughout Lewis's woodpecker core habitat areas and dispersal habitat.

Enhancing connectivity to facilitate range shifts

Actions that may help the Lewis's woodpecker adjust its geographic distribution to track shifts in its areas of climatic suitability include:

- Maintaining and restoring corridors (e.g., landscape integrity corridors; Appendix I.1)) between areas of declining climatic suitability and areas of stability or increasing suitability (Appendix I.3).
- Maintaining and restoring corridors that span elevation gradients (e.g., climate-gradient corridors, Appendix I.1), to promote Lewis's woodpecker dispersal into cooler, higher elevation habitats as the climate warms.
- Focusing habitat retention efforts on riparian areas, which span climatic gradients and are frequently utilized by Lewis's woodpecker for foraging habitat.

Spatial priorities for implementation

Spatial priorities for implementation of the adaptation actions described above include:

- Riparian areas, which span climatic gradients and are frequently utilized by Lewis's woodpecker for foraging habitat.
- Climate-gradient corridors (Appendix I.1), which may help promote Lewis's woodpecker dispersal into cooler, higher elevation habitats as the climate warms.
- Climate-resilient core habitat areas (currently climatically suitable areas that are projected to remain climatically suitable).

Policy considerations

Forest management

Actions for addressing climate impacts on Lewis's woodpecker habitat connectivity through forest management include:

- Reviewing and implementing existing guidance and plans relating to Lewis's woodpecker habitat management. Evaluate existing recommendations for opportunities to address climate impacts.
- Coordinating stewardship and management activities with provincial and local governments, NGOs, tribes and First Nations, and private landowners.

Land and water use planning and zoning

Actions for addressing climate impacts on Lewis's woodpecker connectivity though land and water use planning and zoning include:

- Securing water rights to maintain moisture in riparian areas and wetlands that provide movement corridors and refugia through otherwise unsuitable habitat.

Research needs

Future research that could help inform Lewis's woodpecker habitat connectivity conservation under climate change includes:

- Developing transboundary pest models (e.g., mountain pine beetle, spruce budworm, and western pine beetle). These models could improve assessment of potential impacts, and direct forest health activities toward core areas and corridors identified as being at high risk of insect or pathogen outbreaks.
- Developing transboundary fire models. These models could improve assessment of potential impacts, and direct fire management activities toward core habitat areas and dispersal habitat identified as being at high risk of catastrophic fire.
- Developing fine-scaled, transboundary riparian models. These could help identify high quality riparian corridors that could facilitate movement despite general regional warming.
- Identifying landscape features that may facilitate Lewis's woodpecker movement, and evaluating the utility of corridors (e.g., landscape integrity corridors (Appendix I.1)) for promoting dispersal.
- Identifying potential climate impacts on specific core habitat areas and corridors. Overlay projected changes in climate with landscape integrity corridor networks (Appendix I.1) to quantify expected impacts on specific areas within the network. This may help direct adaptation actions to appropriate areas.
- Identifying climate resilient landscape integrity core habitat areas and corridors. Overlay the corridor network (Appendix I.1) with climatic niche models (Appendix I.3), projected changes in vegetation (Appendix I.4) and climate variables (Appendix I.6); core areas and corridors within the current range that are projected by multiple models to retain suitable climatic conditions and vegetation, and to see the least change in relevant climatic variables, may be considered most likely to be resilient. Climate-resilient core habitat areas and corridors may be used to identify priority areas for the adaptation actions described above.
- Identifying corridors between locations with projected declines in climatic suitability and areas with projected stable or improving climatic suitability. Use climatic niche models (Appendix I.3) and vegetation projections (Appendix I.4) to identify potentially stable or improving locations. Use landscape integrity corridor models (Appendix I.1) to identify potential corridors for connecting vulnerable Lewis's woodpecker core habitat areas to areas projected to remain climatically suitable or become newly suitable.

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Glossary of Terms

Assisted migration – Species and populations are deliberately planted or transported to new suitable habitat locations, typically in response to declines in historic habitat quality resulting from rapid environmental change, principally climate change.

Centrality — Refers to a group of landscape metrics that rank the importance of habitat patches or linkages in providing movement across an entire network, i.e., as "gatekeepers" of flow across a landscape.[iv]

Connectivity — Most commonly defined as the degree to which the landscape facilitates or impedes movement among resource patches.[v] Can be important for maintaining ecological, population-level, or evolutionary processes.

Core Areas — Large blocks (10,000+ acres) of contiguous lands with relatively high landscape permeability.

Corridor — Refers to modeled movement routes or physical linear features on the landscape (e.g., continuous strips of riparian vegetation or transportation routes). In this document, the term "corridor" is most often used in the context of modeled least-cost corridors, i.e., the most efficient movement pathways for wildlife and ecological processes that connect HCAs or core areas. These are areas predicted to be important for migration, dispersal, or gene flow, or for shifting ranges in response to climate change and other factors affecting the distribution of habitat.

Desiccation – Extreme water deprivation, or process of extreme drying.

Dispersal — Relatively permanent movement of an individual from an area, such as movement of a juvenile away from its place of birth.

Fracture Zone — An area of reduced permeability between core areas. Most fracture zones need significant restoration to function as reliable linkages. Portions of a fracture zone may be potential linkage zones.

Habitat Connectivity — See Connectivity.

Landscape Connectivity — See Connectivity.

Permeability — The ability of a landscape to support movement of plants, animals, or processes.

Pinch point — Portion of the landscape where movement is funneled through a narrow area. Pinch points can make linkages vulnerable to further habitat loss because the loss of a small area can sever the

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[iv] Carroll, C. 2010. Connectivity analysis toolkit user manual. Version 1.1. Klamath Center for Conservation Research, Orleans, California. Available at www.connectivitytools.org (accessed January 2016).
[v] Taylor, P. D., L. Fahrig, K. Henein, and G. Merriam. 1993. Connectivity is a vital element of landscape structure. *Oikos* 68: 571-573.

linkage entirely. Synonyms are bottleneck and choke point.

Refugia – Geographical areas where a population can survive through periods of unfavorable environmental conditions (e.g., climate-related effects).

Thermal barriers – Water temperatures warm enough to prevent migration of a given fish species. These barriers can prevent or delay spawning for migrating salmonids.

Appendices I.1-6

Appendices include all materials used to identify potential climate impacts on habitat connectivity for case study species, vegetation systems, and regions. For Lewis's woodpecker, these materials include:

Appendix I.1. Habitat connectivity models
Appendix I.2. Conceptual model of habitat connectivity
Appendix I.3. Climatic niche models
Appendix I.4. Projected changes in vegetation communities
Appendix I.5. Projected changes in probability of mountain pine beetle survival
Appendix I.6. Projected changes in relevant climatic variables

All maps included in these appendices are derived from a few primary datasets, chosen because they are freely available, span all or part of the transboundary region, and reflect the expertise of project science partners. These sources include habitat connectivity models produced by the Washington Connected Landscapes Project,[7,8] future climate projections from the Integrated Scenarios of the Pacific Northwest Environment[9] and the Pacific Climate Impacts Consortium's Regional Analysis Tool,[10] and models of projected range shifts and vegetation change produced as part of the Pacific Northwest Climate Change Vulnerability Assessment.[11]

All maps are provided at three geographic extents corresponding to the distinct geographies of the three project partnerships (Fig. I.2):

i. **Okanagan Nation Territory**, the assessment area for project partners: Okanagan Nation Alliance and its member bands and tribes, including Colville Confederated Tribes.
ii. **The Okanagan-Kettle Region**, the assessment area for project partners: Transboundary Connectivity Working Group (i.e., the Washington Habitat Connectivity Working Group and its BC partners).
iii. **The Washington-British Columbia Transboundary Region**, the assessment area for project partners: BC Parks; BC Forests, Lands, and Natural Resource Operations; US Forest Service; and US National Park Service.

All project reports, data layers, and associated metadata are freely available online at: https://nplcc.databasin.org/galleries/5a3a424b36ba4b63b10b8170ea0c915e

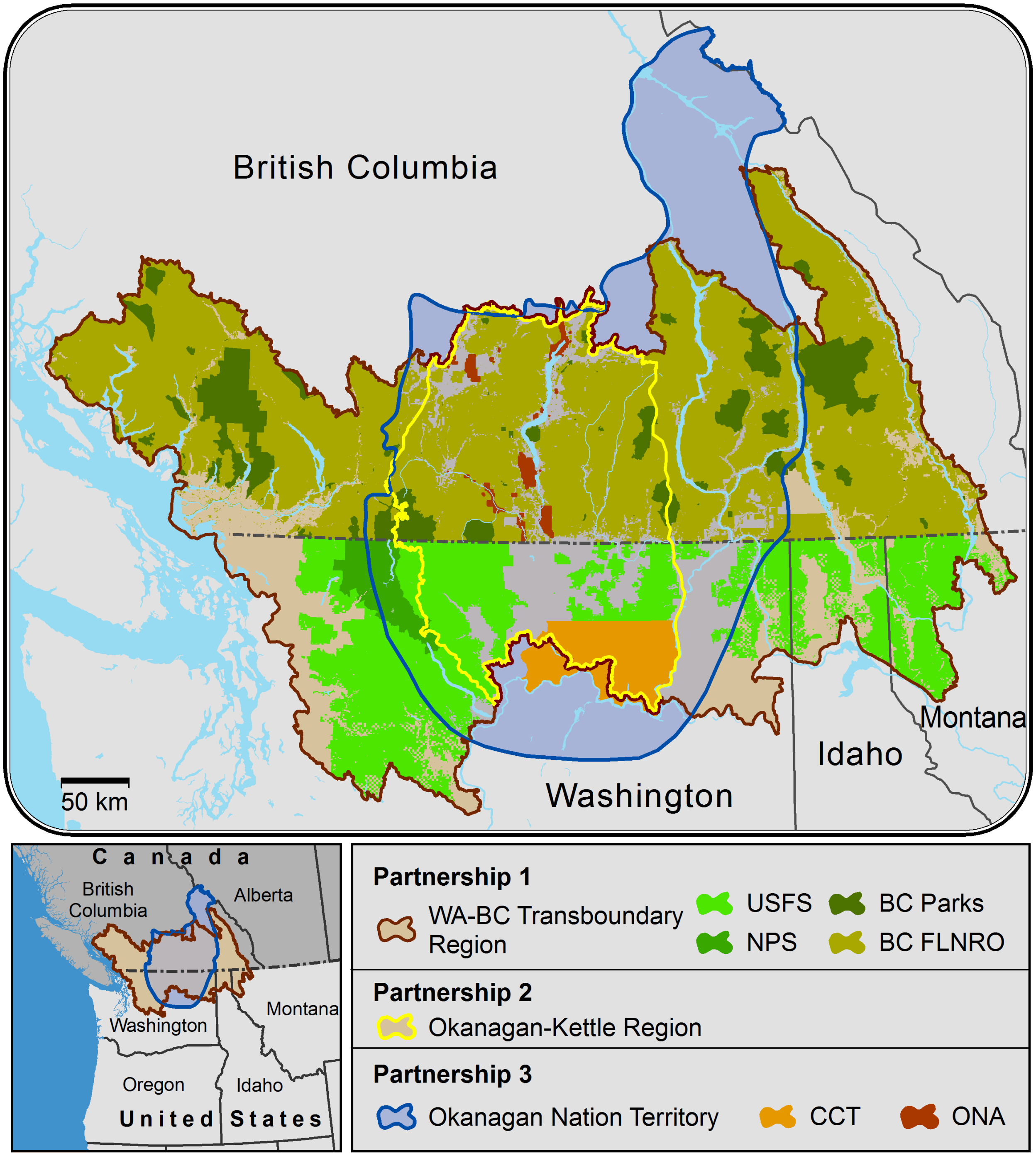


Figure I.2. Project partners and assessment areas.

Appendix I.1. Habitat Connectivity Models

Habitat connectivity models are available from the Washington Connected Landscapes Project.[vi] These models can be used to prioritize areas for maintaining and restoring habitat connectivity now and in the future as the climate changes. Available models include species corridor networks, landscape integrity corridor networks, and climate-gradient corridor networks. These models are available at two distinct scales (though for many species, only one scale is available or was selected for use by project participants): 1) **WHCWG Statewide** models span Washington State and surrounding areas of Oregon, Idaho, and British Columbia; 2) **WHCWG Columbia Plateau** models span the Columbia Plateau ecoregion within Washington State, and do not extend into British Columbia.

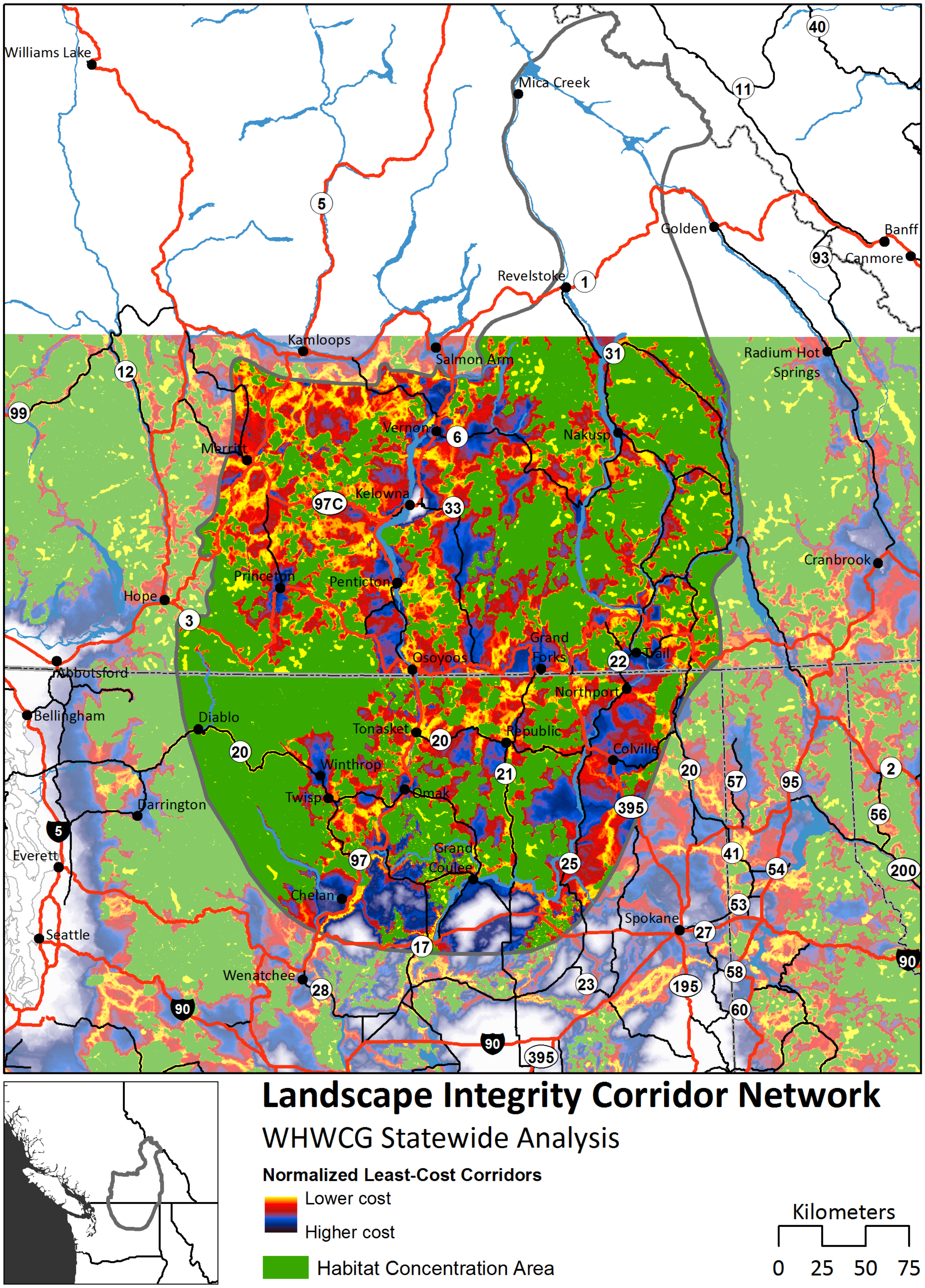
a) **WHCWG Statewide Analysis: Landscape Integrity Corridor Network.[7]** This map shows corridor networks connecting core habitat areas (green polygons) for areas of high landscape integrity (e.g., areas with few roads, agricultural areas, or urban areas). Corridors are represented as yellow areas, with resistance to movement increasing as yellow transitions to blue. Green areas represent large, contiguous core areas of high landscape integrity. The northern extent of this analysis falls just north of Kamloops, BC.

b) **WHCWG Statewide Analysis: Climate-Gradient Corridor Network (Temperature + Landscape Integrity).[8]** This map shows corridors (glowing white areas, with resistance to movement increasing as white fades to black) connecting core habitat areas (polygons, shaded to reflect mean annual temperatures) that are of high landscape integrity (i.e., have low levels of human modification) and differ in temperature by >1 ^{o}C. These corridors thus allow for movement between relatively warmer and cooler core habitat areas, while avoiding areas of low landscape integrity (e.g., roads, agricultural areas, urban areas), and minimizing major changes in temperature along the way (e.g., crossing over cold peaks or dipping into warm valleys). The northern extent of this analysis falls just north of Kamloops, BC.

[vi] For detailed methodology and data layers see http://www.waconnected.org.

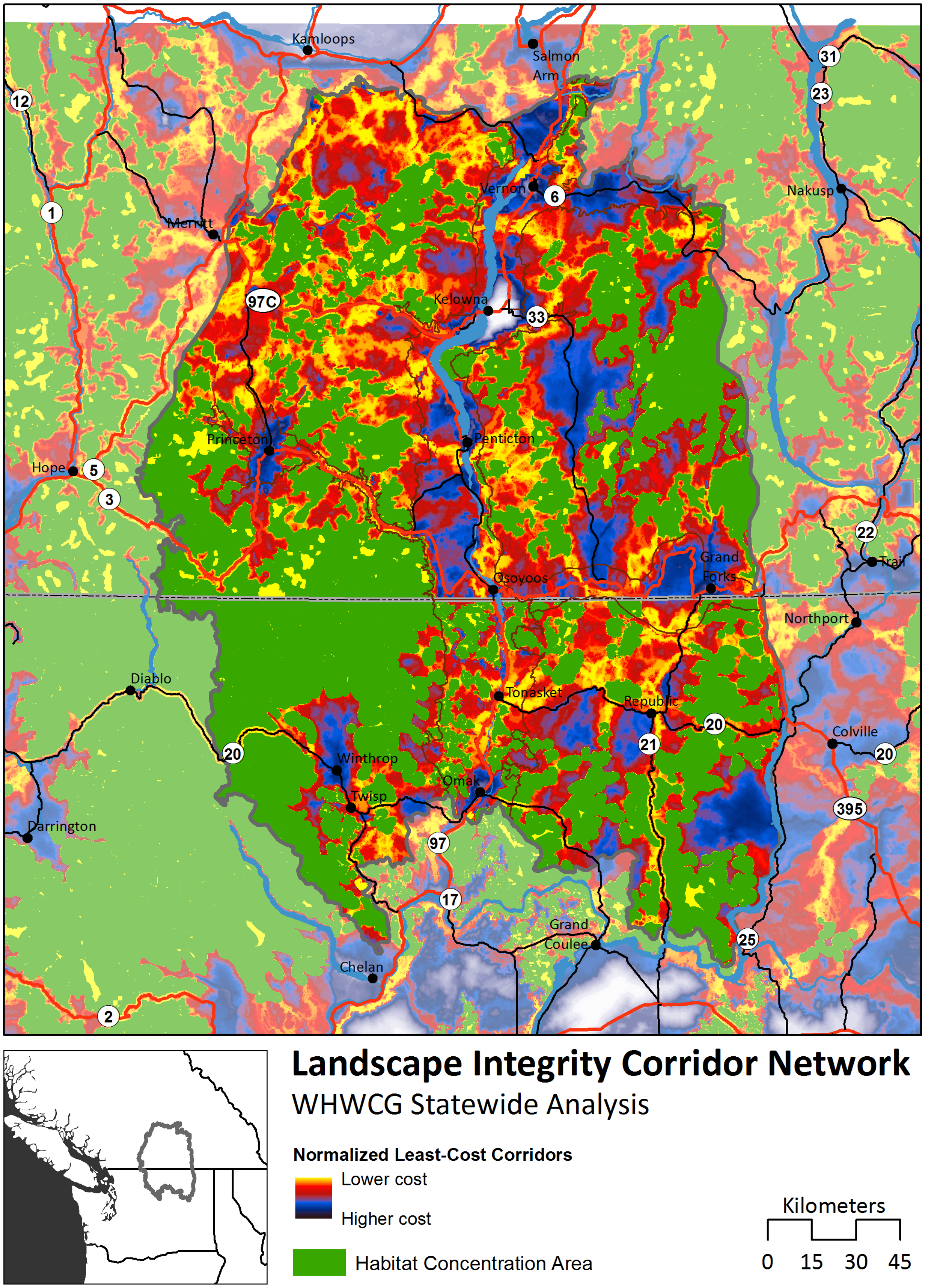
Appendix I.1a. WHCWG Statewide Analysis: Landscape Integrity Corridor Network

i) Extent: Okanagan Nation Territory



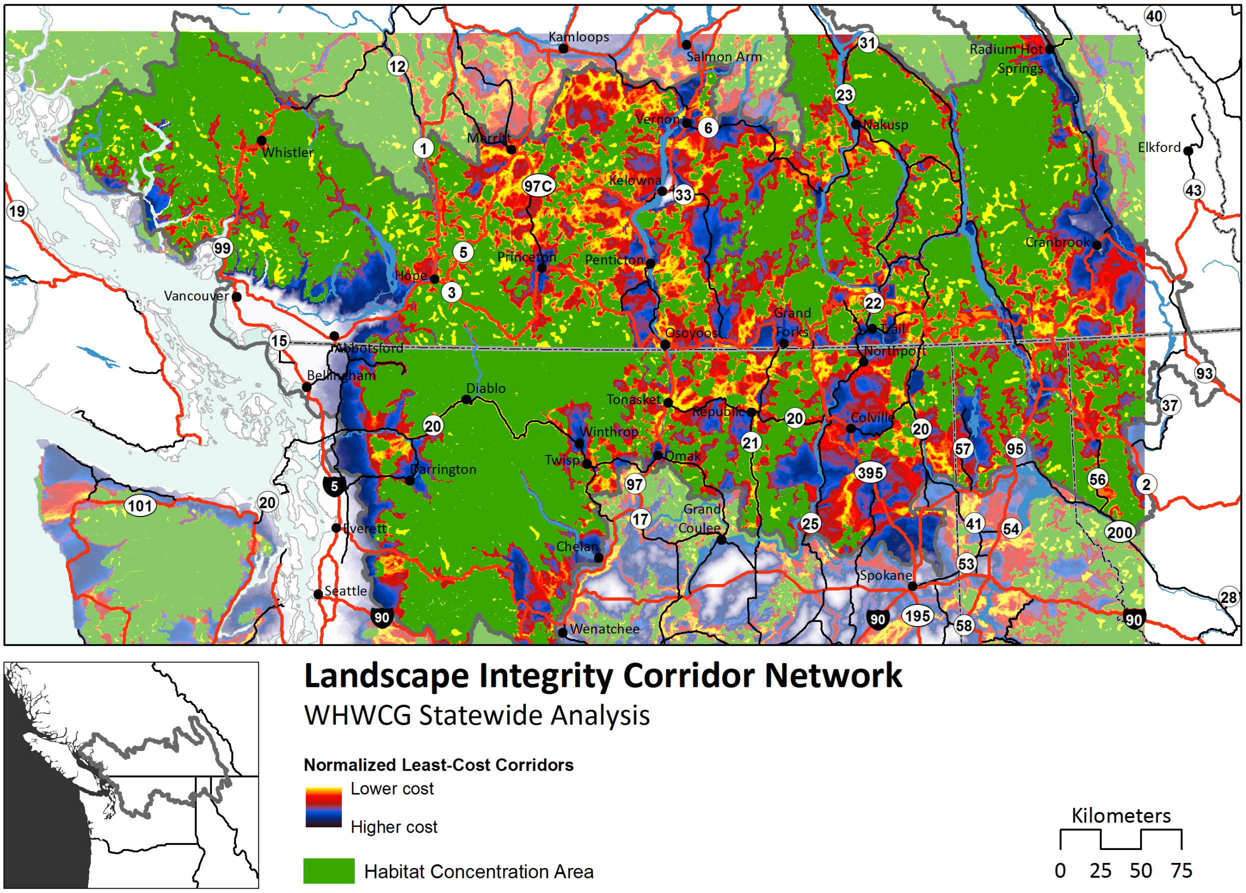
Appendix I.1a. WHCWG Statewide Analysis: Landscape Integrity Corridor Network

ii) Extent: Okanagan-Kettle Region



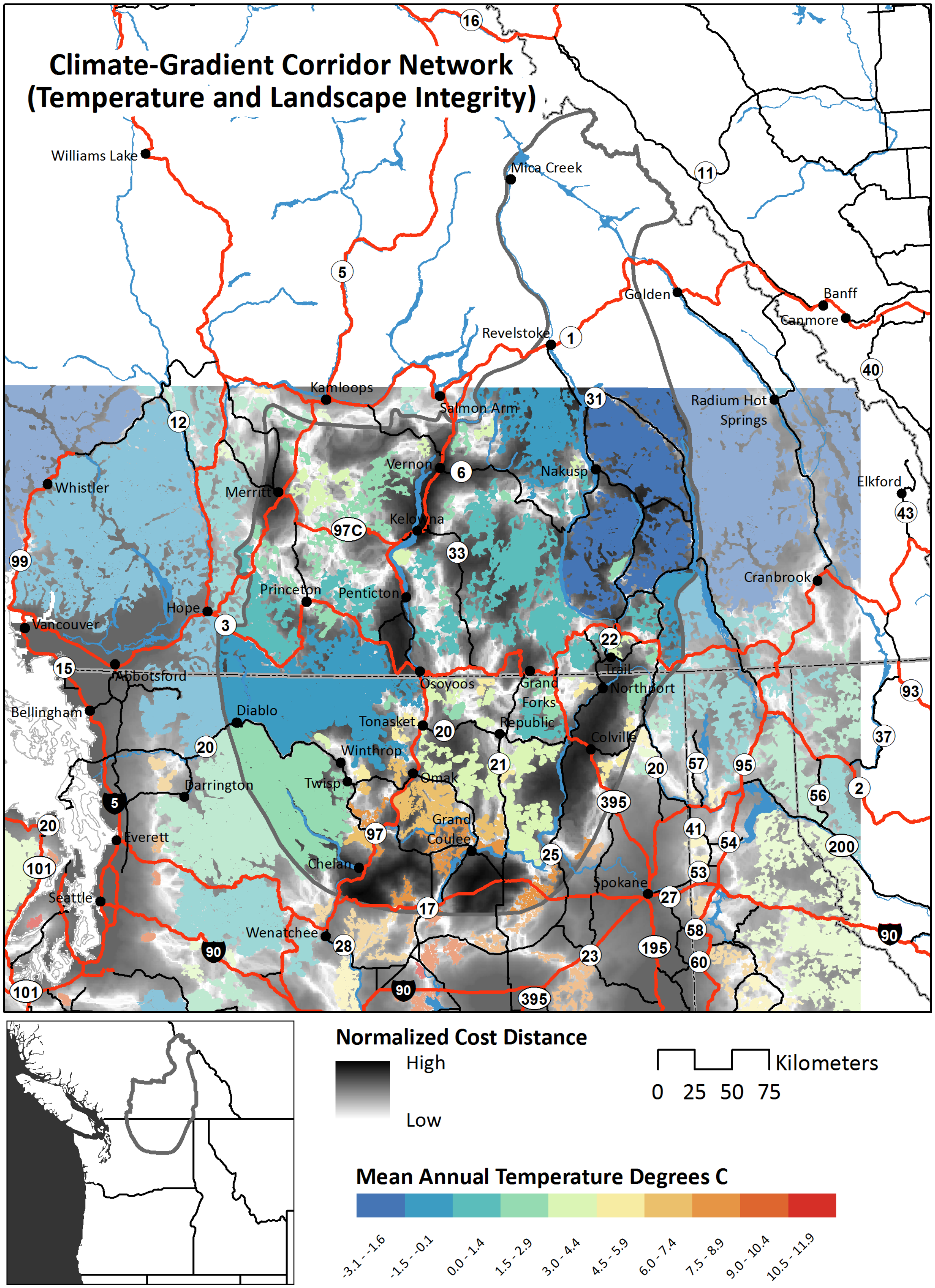
Appendix I.1a. WHCWG Statewide Analysis: Landscape Integrity Corridor Network

iii) Extent: Washington-British Columbia Transboundary Region



Appendix I.1b. WHCWG Statewide Analysis: Climate-Gradient Corridor Network (Temperature + Landscape Integrity)

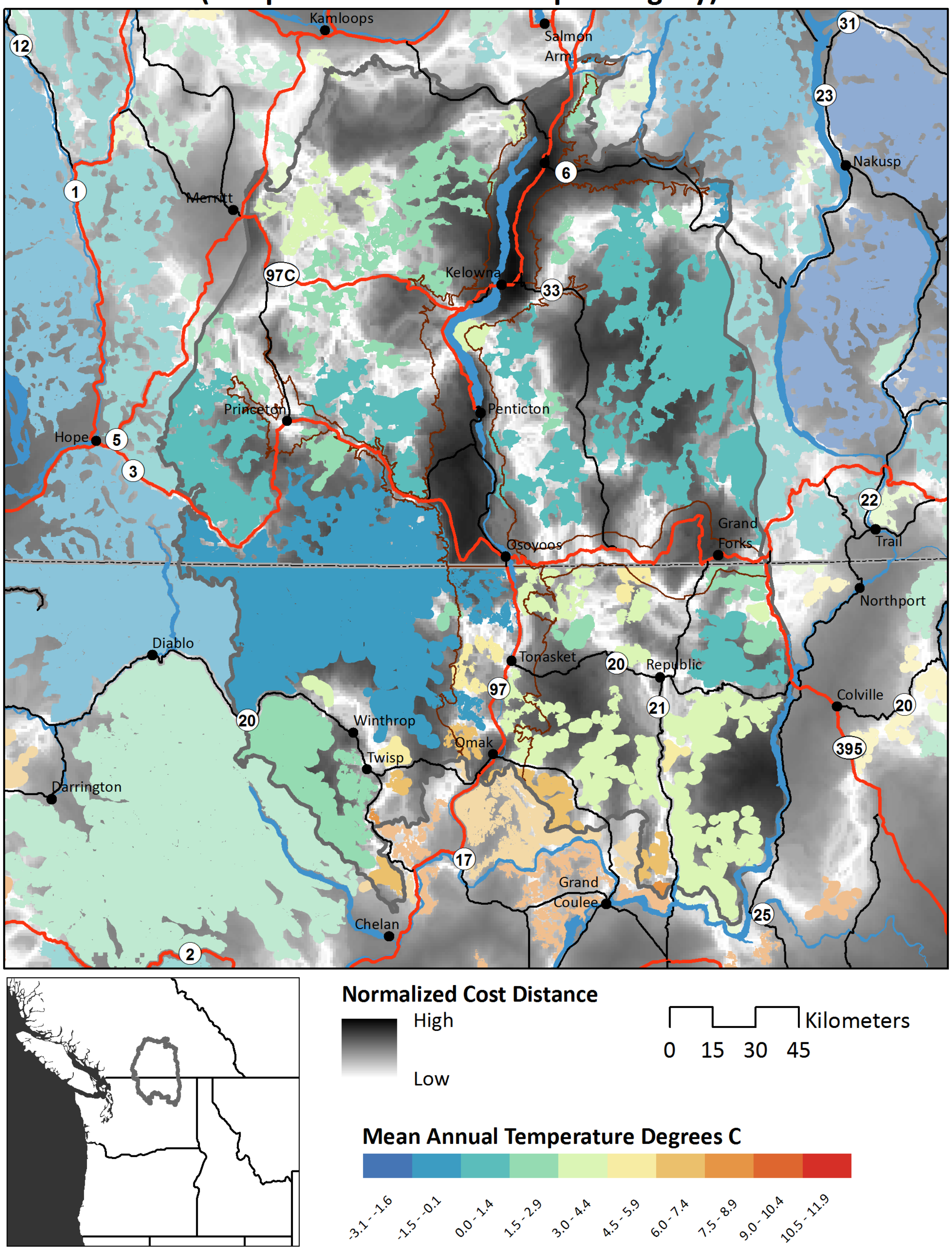
i) Extent: Okanagan Nation Territory



Appendix I.1b. WHCWG Statewide Analysis: Climate-Gradient Corridor Network (Temperature + Landscape Integrity)

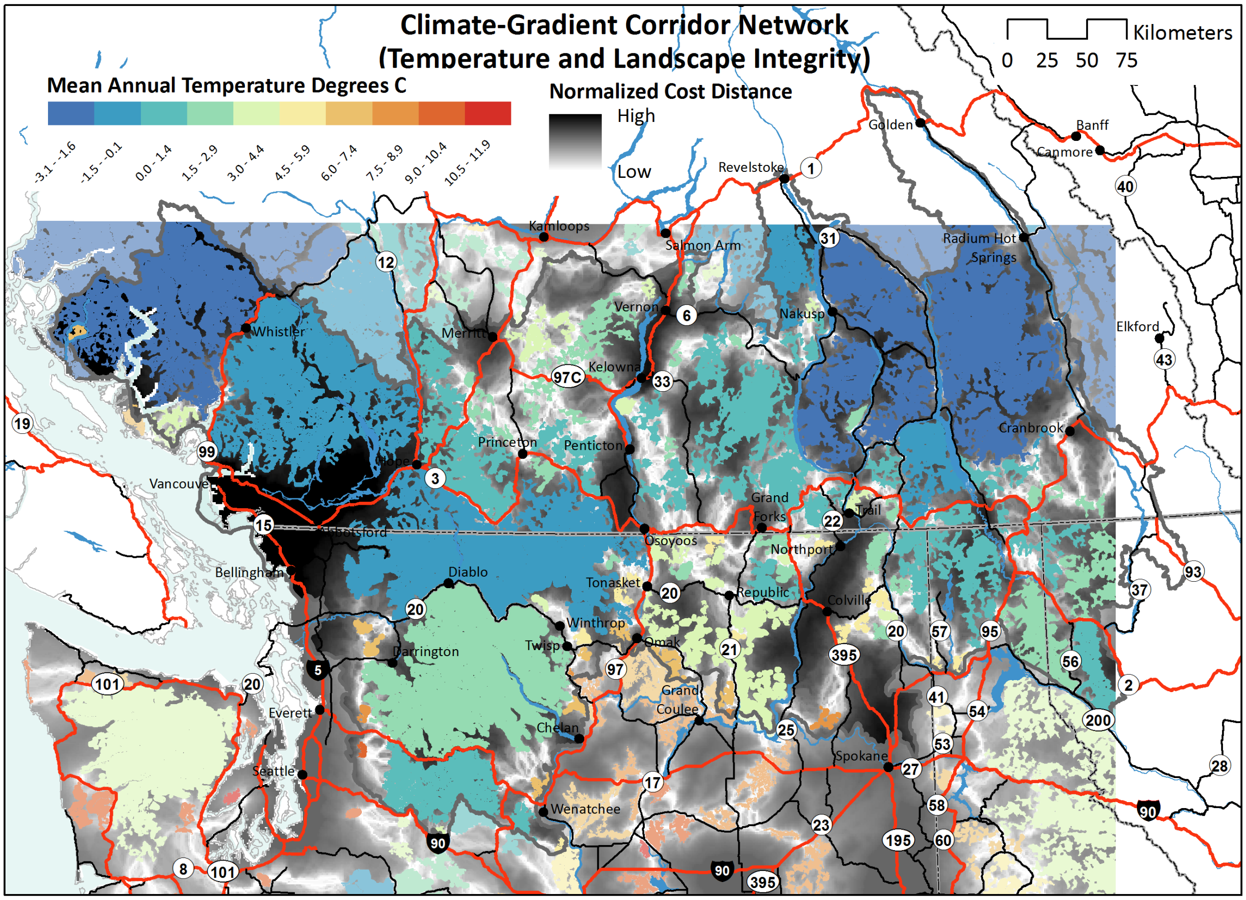
ii) Extent: Okanagan-Kettle Region

Climate-Gradient Corridor Network (Temperature and Landscape Integrity)



Appendix I.1b. WHCWG Statewide Analysis: Climate-Gradient Corridor Network (Temperature + Landscape Integrity)

iii) Extent: Washington-British Columbia Transboundary Region



Appendix I.2. Conceptual Model of Habitat Connectivity

To identify potential climate impacts on transboundary Lewis's woodpecker habitat connectivity, project partners created a conceptual model that identifies the key landscape features and processes expected to influence Lewis's woodpecker habitat connectivity, which of those are expected to be influenced by climate, and how. Simplifying complex ecological systems in such a way can make it easier to identify specific climate impacts and adaptation actions. For this reason, conceptual models have been promoted as useful adaptation tools, and have been applied in a variety of other systems.[6] The Lewis's woodpecker conceptual model was developed using peer-reviewed articles and reports, project participant expertise, and review by species experts. That said, the resulting model is intentionally simplified, and should not be interpreted to represent a comprehensive assessment of the full suite of landscape features and processes contributing to Lewis's woodpecker habitat connectivity.

Conceptual models illustrate the relationships between the key landscape features (white boxes), ecological processes (rounded corner purple boxes), and human activities (rounded corner blue boxes) that influence the quality and permeability of core habitat and dispersal habitat for a given species. Climatic variables for which data on projected changes are available are highlighted with a yellow outline. Green arrows indicate a positive correlation between linked variables (i.e., as variable x increases variable y increases); note that a positive correlation is not necessarily beneficial to the species. Red arrows indicate a negative relationship between variables (i.e., as variable x increases, variable y decreases); again, negative correlations are not necessarily harmful to the species.

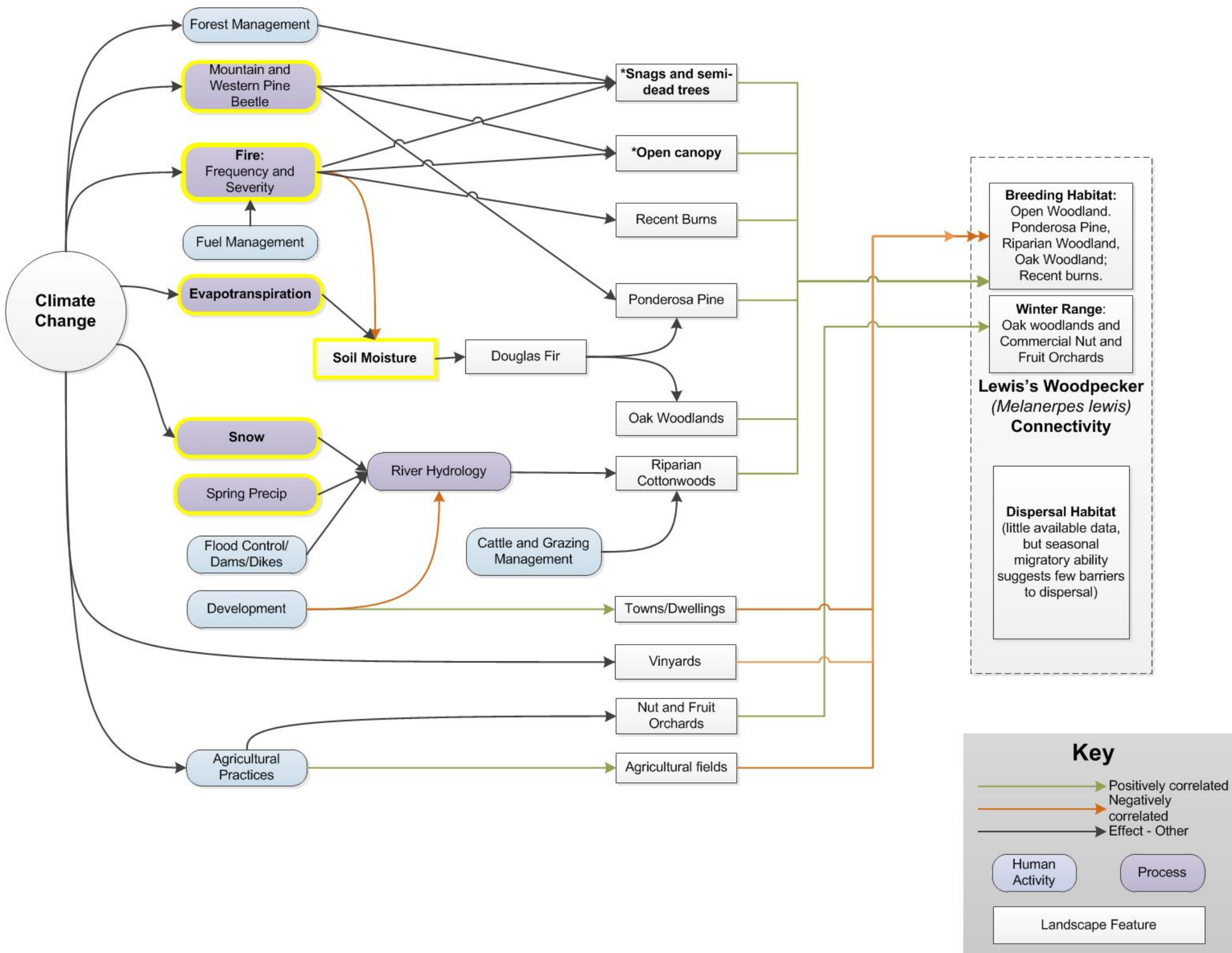
Expert reviewers for the Lewis's woodpecker conceptual model included:

- Alison Peatt, RPBio, Environmental planner for South Okanagan-Similkameen communities
- Les Gyug, Okanagan Wildlife Consulting
- Lower Similkameen Indian Band (staff member)

Key references used to create the Lewis's woodpecker conceptual model included:

Abele, S.C., V.A. Saab, and E.O. Garton. 2004. Lewis's Woodpecker (Melanerpes lewis): a technical conservation assessment. [Online]. USDA Forest Service, Rocky Mountain Region. Available at: http://www.fs.fed.us/r2/projects/scp/assessments/lewisswoodpecker.pdf (Accessed April 29, 2016)

Appendix I.2. Conceptual Model of Lewis's Woodpecker Habitat Connectivity



Appendix I.3. Climatic Niche Models

Climatic niche models (CNM) mathematically define the climatic conditions within each species' current geographic distribution, and then apply projected climate changes to identify where on the landscape those climate conditions are projected to be located in the future. These maps show CNM results based on results from two CMIP3 Global Circulation Models (GCMs): CGCM3.1(T47) and UKMO-HadCM3.[vii] Both models use the A2 (high) emissions scenario.[viii] CNMs are based on climate conditions alone and do not account for dispersal ability, genetic adaptation, interspecies interactions, or other aspects of habitat suitability. Once projected range shifts were modeled, current land uses and projected vegetation types (identified using Shafer et al. 2015[ix]) that are unlikely to support species occurrence were removed. For example, areas currently defined as urban were removed for species unable to live in urban landscapes, and grassland habitats were removed for forest-dependent species. Both would be shown as unsuitable.

Dark gray areas indicate areas of the species' current range that are projected to remain climatically suitable by both GCMs (i.e., range is expected to remain "stable"). Dark pink areas are projected to become less climatically suitable by both GCMs (i.e., range is expected to "contract"). Light pink areas are projected to become less suitable under one model but remain stable under the other. Dark green areas are areas that are not within the species' current range but are projected to become climatically suitable by both GCMs (i.e., the range is expected to "expand"). Light green areas are projected to become climatically suitable by one GCM, but not the other.

[vii] CGCM3.1(T47) and UKMO-HadCM3 are two Global Circulation Models (GCMs) which each project different potential future climate scenarios. The UKMO-HadCM3 model projects a much hotter and drier summer, while the CGCM3.1(T47) projects greater precipitation increases in spring, summer and fall. For these reasons, the UKMO-HadCM3 could be considered a "hot-dry" future, while the CGCM3.1(T47) could be considered a "warm-wet" future within the Pacific Northwest.

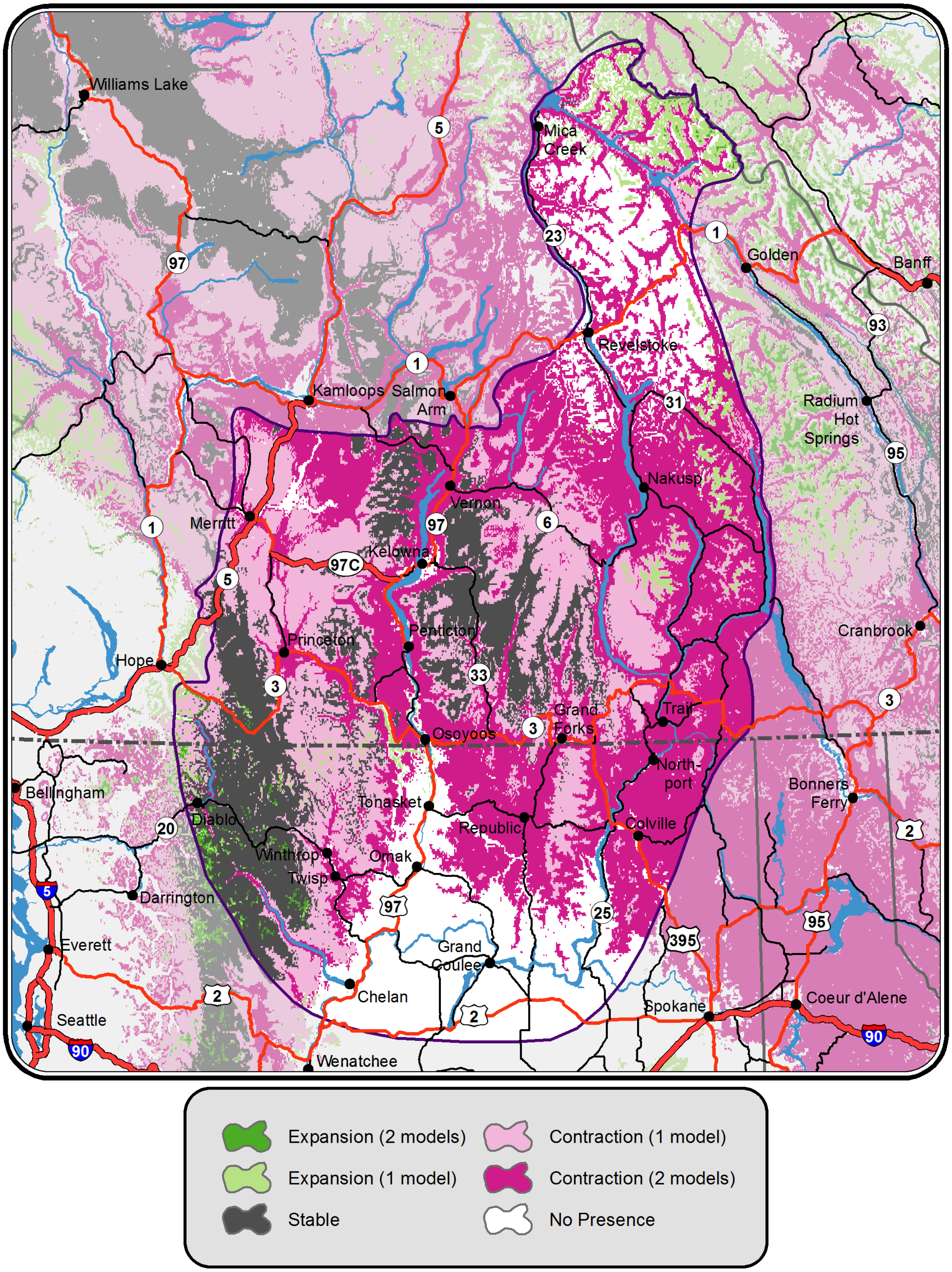
[viii] Emissions scenarios were developed by climate modeling centers for use in modeling global and regional climate-related effects. A2 is a high, "business as usual" scenario in which emissions of greenhouse gases continue to rise until the end of the 21st century, and atmospheric CO_2 concentrations more than triple by 2100 relative to pre-industrial levels.

[ix] Shafer, S.L., Bartlein, P.J , Gray, E.M., and R.T. Pelltier. 2015. Projected future vegetation changes for the northwest United States and southwest Canada at a fine spatial resolution using a dynamic global vegetation model. *PLoS ONE* 10: e0138759. doi:10.1371/journal.pone.0138759

Appendix I.3. Lewis's Woodpecker Climatic Niche Model

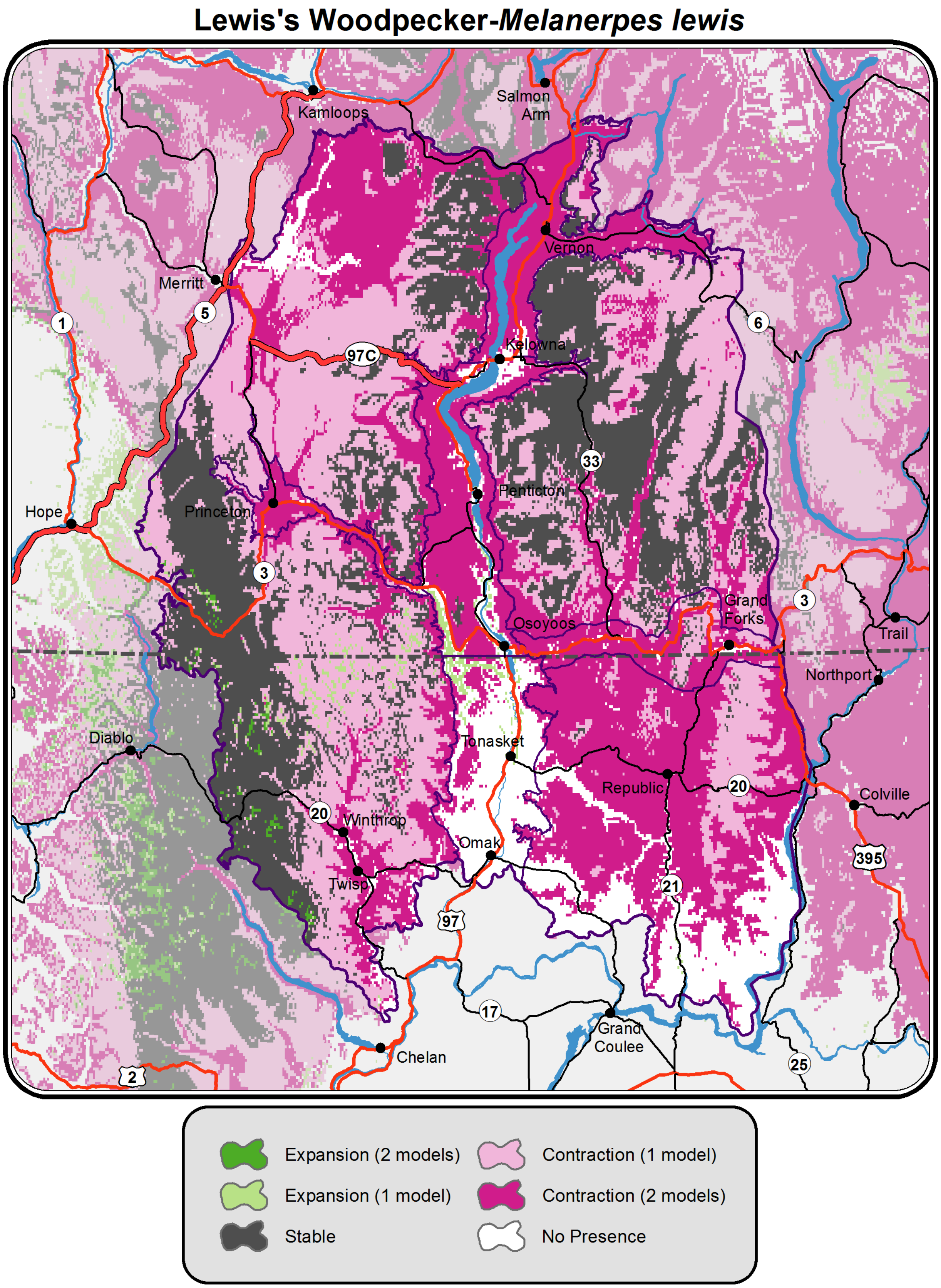
i) Extent: Okanagan Nation Territory

Lewis's Woodpecker-*Melanerpes lewis*



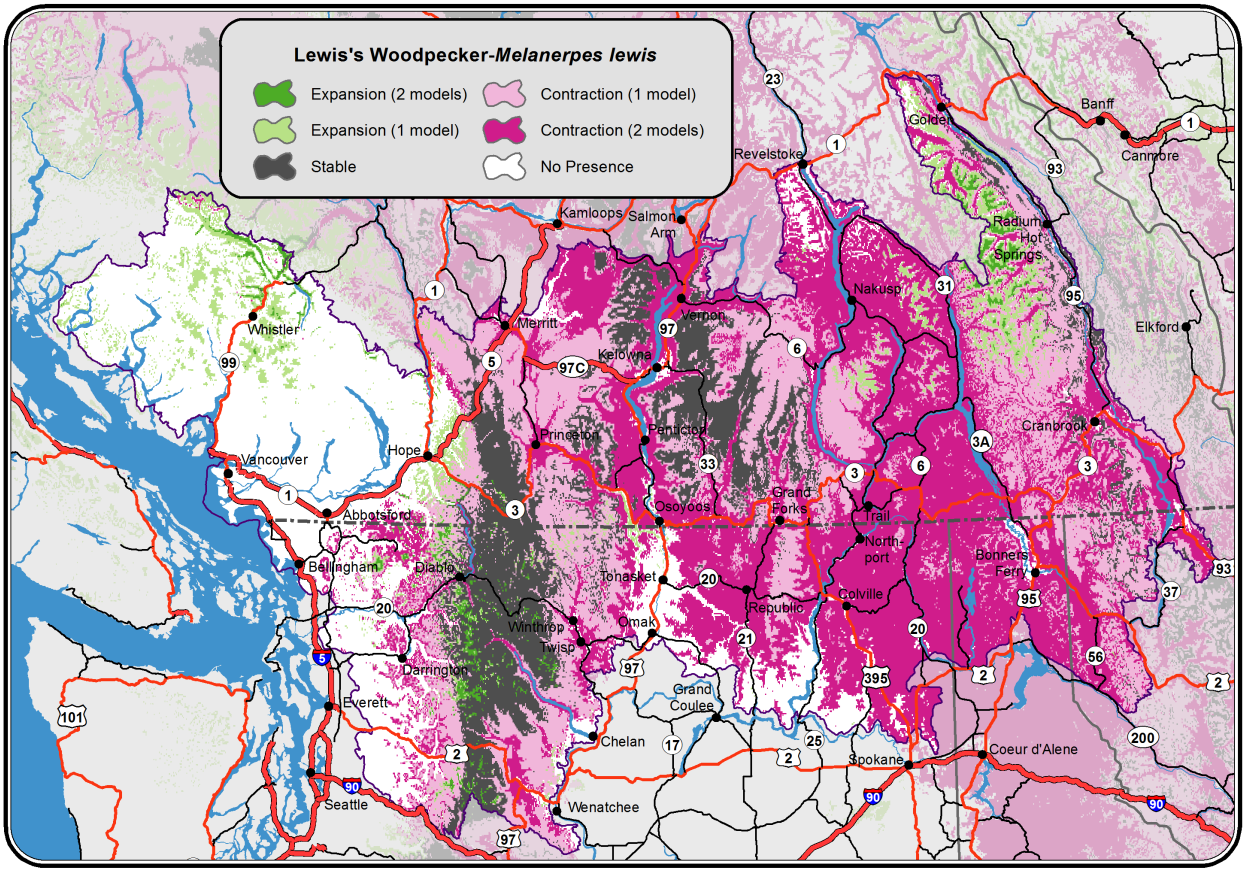
Appendix I.3. Lewis's Woodpecker Climatic Niche Model

ii) Extent: Okanagan-Kettle Region



Appendix I.3. Lewis's Woodpecker Climatic Niche Model

iii) Extent: Washington-British Columbia Transboundary Region



Appendix I.4. Projected Changes in Vegetation

Two types of models are available that project future changes in vegetation that could affect a species' habitat connectivity: climatic niche models and mechanistic models. Climatic niche vegetation models mathematically define the climatic conditions within a given vegetation type's current distribution and then project where on the landscape those conditions are expected to occur in the future. These models do not incorporate other important factors that determine vegetation such as soil suitability, dispersal, competition, and fire. In contrast, mechanistic vegetation models do incorporate these ecological processes, as well as projected climate changes and the potential effects of carbon dioxide fertilization. However, mechanistic models only project changes to very general vegetation types (e.g., cold forest, shrub steppe, or grassland). Both types of models included below show vegetation model results based on results from two CMIP3 Global Circulation Models (GCMs): CGCM3.1(T47) and UKMO-HadCM3.[x] Both models also use the A2 (high) emissions scenario.[xi]

a) **Biome Climatic Niche Vegetation Model.**[xii] This climatic niche vegetation model shows the projected response of biomes or forest types to projected climate change.

b) **Mechanistic Vegetation Model.**[xiii] This mechanistic vegetation model shows simulated vegetation composition and distribution patterns under climate change.

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[x] CGCM3.1(T47) and UKMO-HadCM3 are two Global Circulation Models (GCMs) which each project different potential future climate scenarios. The UKMO-HadCM3 model projects a much hotter and drier summer, while the CGCM3.1(T47) projects greater precipitation increases in spring, summer and fall. For these reasons, the UKMO-HadCM3 could be considered a "hot-dry" future, while the CGCM3.1(T47) could be considered a "warm-wet" future within the Pacific Northwest.

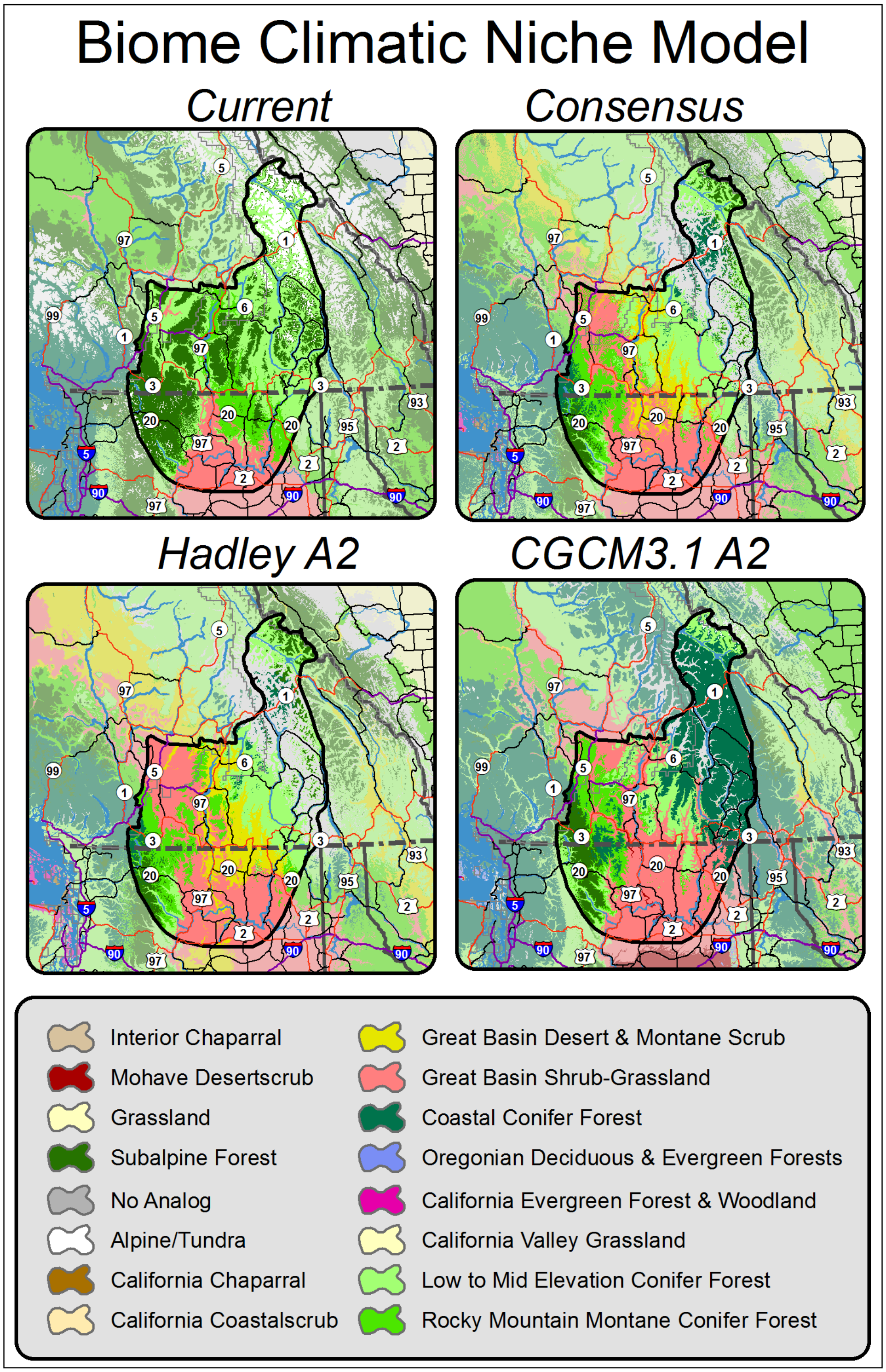
[xi] Emissions scenarios were developed by climate modeling centers for use in modeling global and regional climate-related effects. A2 is a high, "business as usual" scenario in which emissions of greenhouse gases continue to rise until the end of the 21st century, and atmospheric CO_2 concentrations more than triple by 2100 relative to pre-industrial levels.

[xii] Rehfeldt, G.E., Crookston, N.L., Sánez-Romero, C., Campbell, E.M. 2012. North American vegetation model for land-use planning in a changing climate: a solution to large classification problems. *Ecological Applications* 22: 119-141.

[xiii] Shafer, S.L., Bartlein, P.J , Gray, E.M., and R.T. Pelltier. 2015. Projected future vegetation changes for the Northwest United States and Southwest Canada at a fine spatial resolution using a dynamic global vegetation model. *PLoS ONE* 10: e0138759. doi:10.1371/journal.pone.0138759.

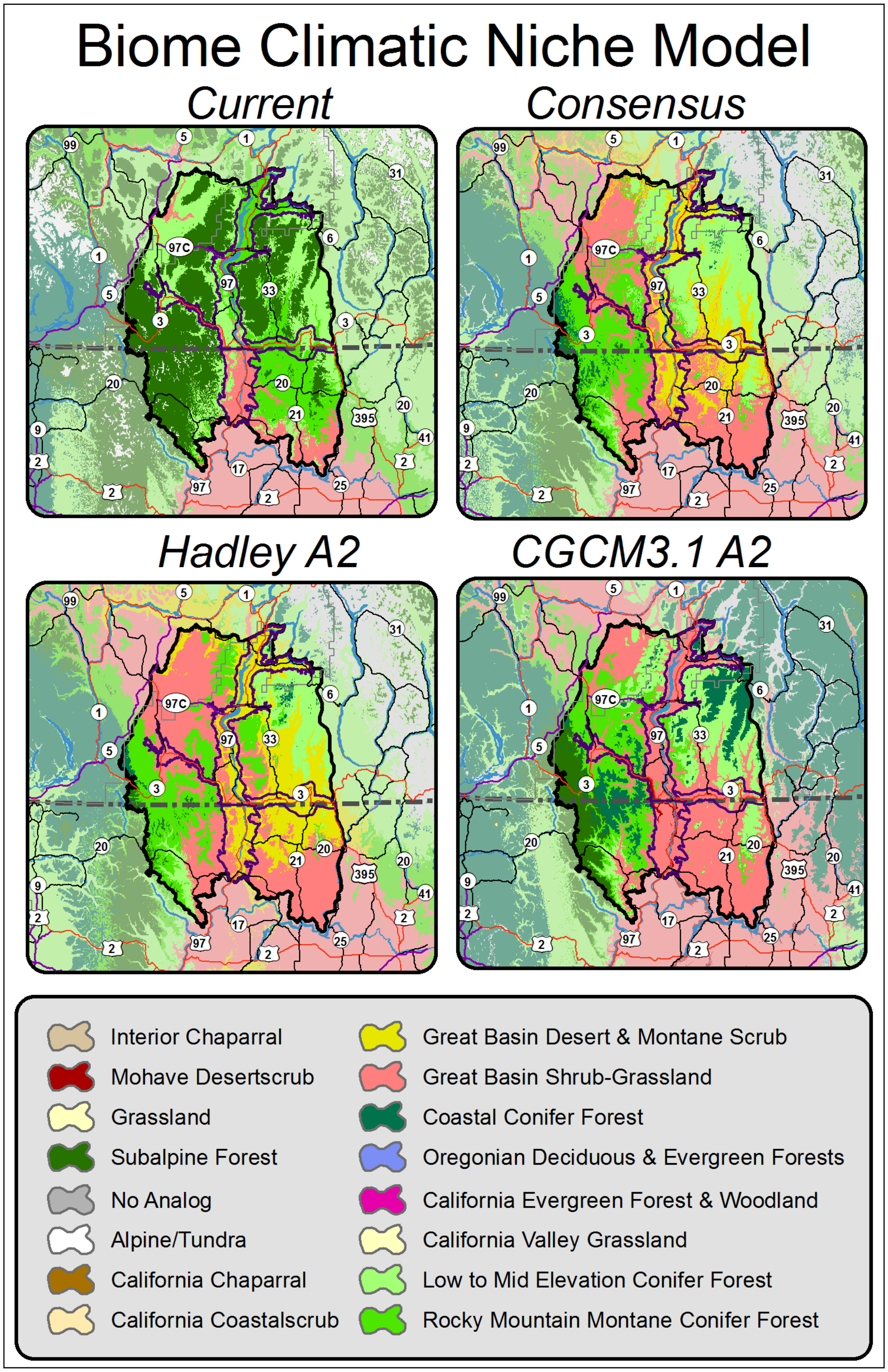
Appendix I.4a. Biome Climatic Niche Model

i) Extent: Okanagan Nation Territory



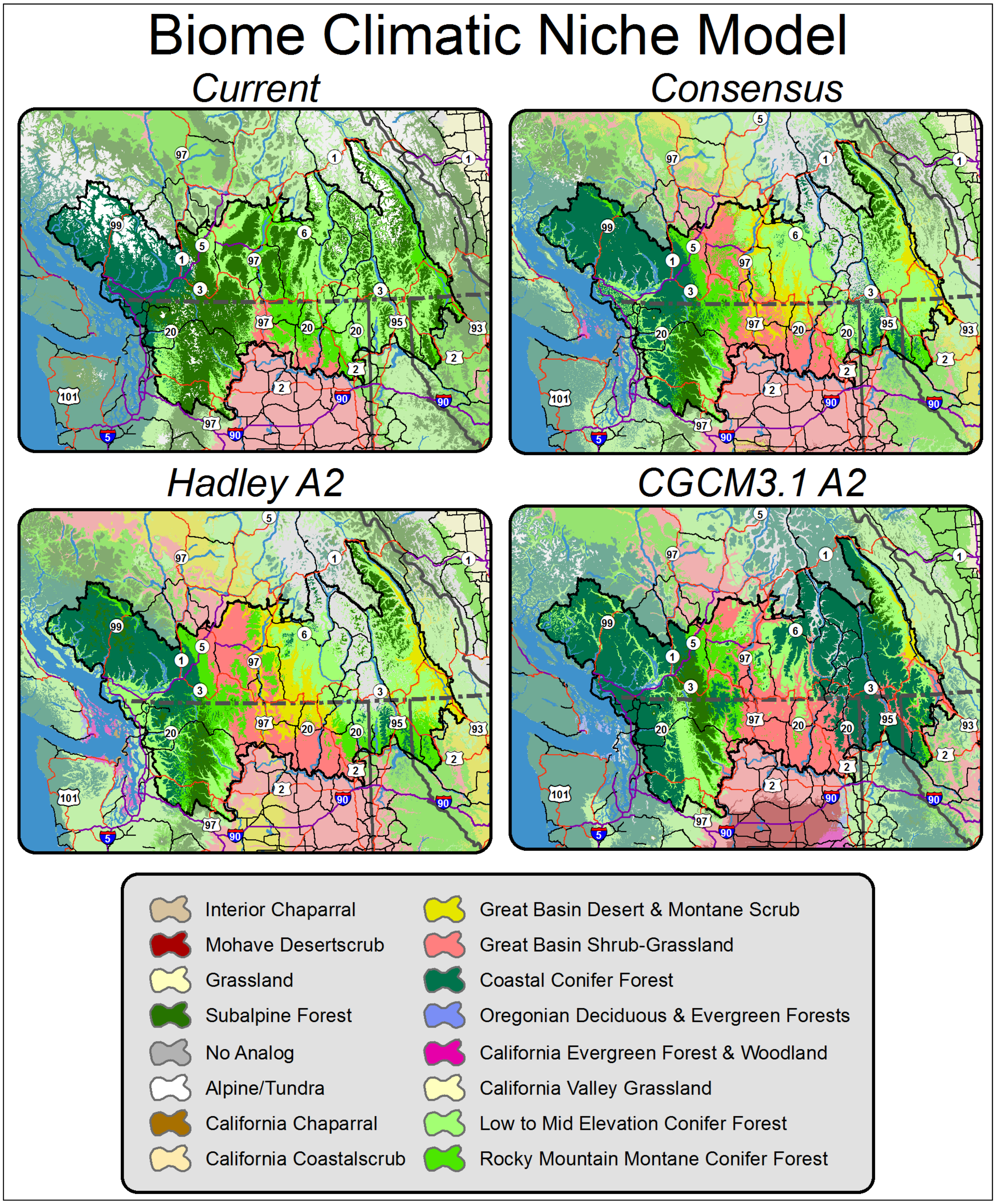
Appendix I.4a. Biome Climatic Niche Model

ii) Extent: Okanagan-Kettle Region



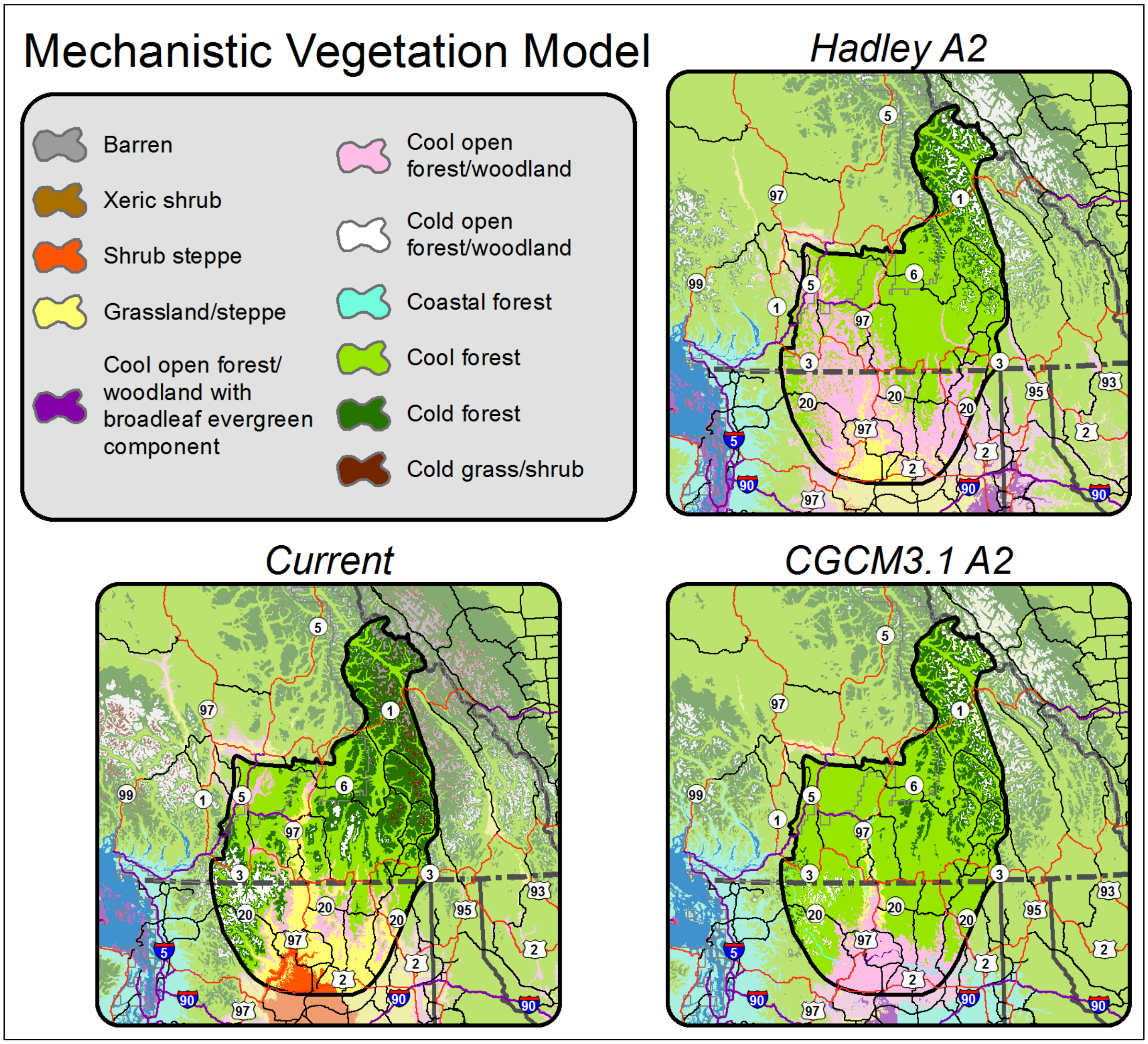
Appendix I.4a. Biome Climatic Niche Model

iii) Extent: Washington-British Columbia Transboundary Region



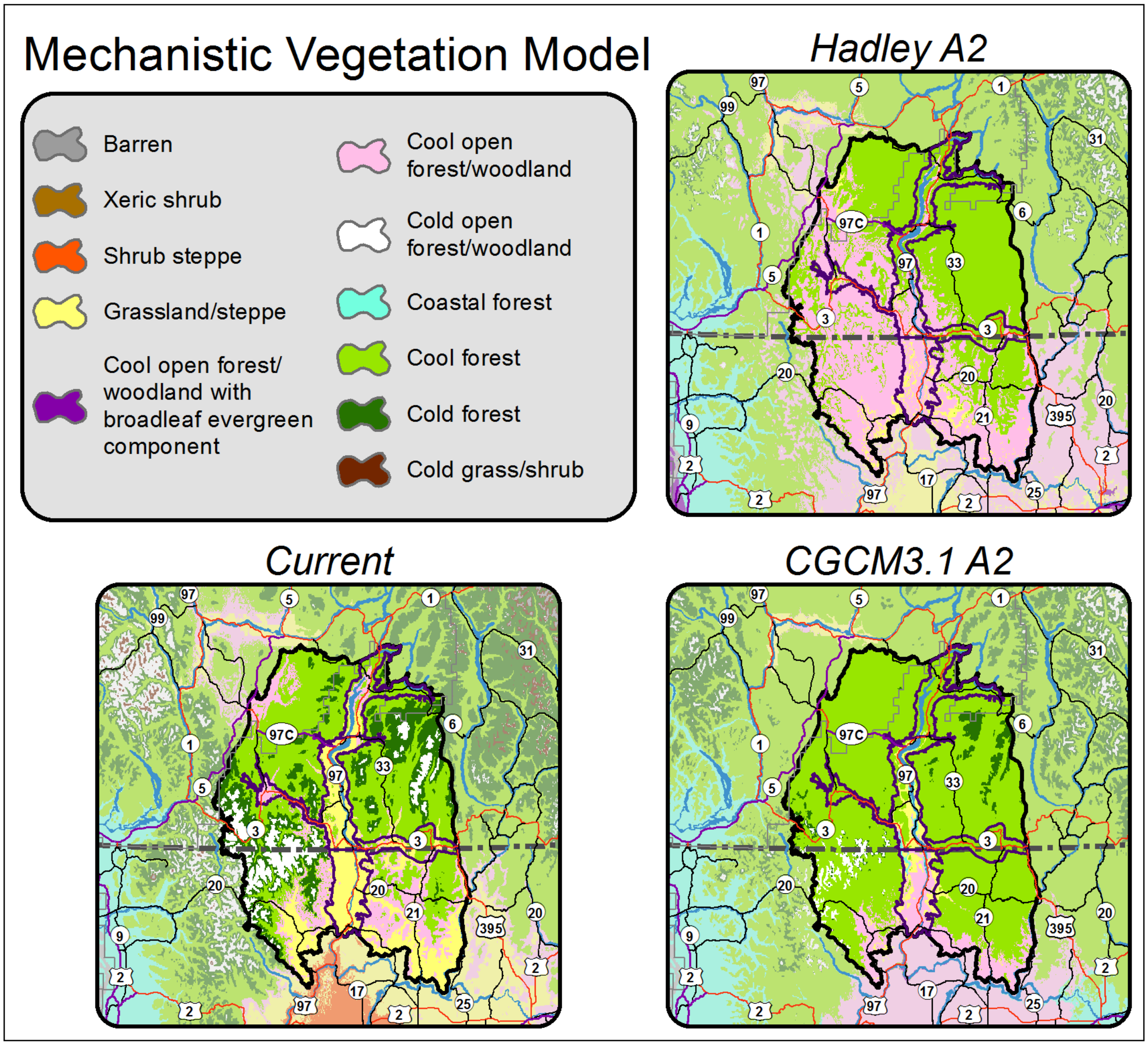
Appendix I.4b. Mechanistic Vegetation Model

i) Extent: Okanagan Nation Territory



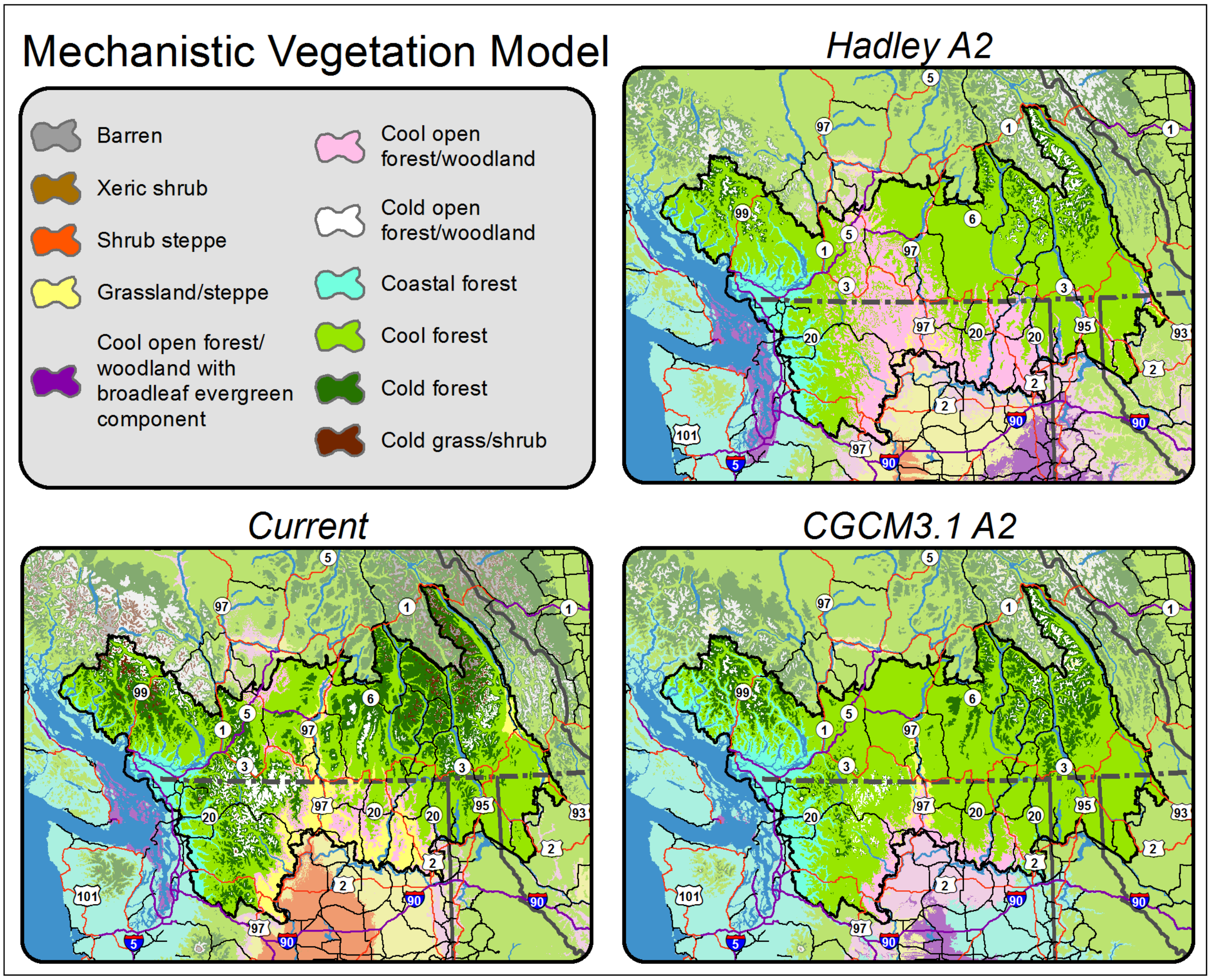
Appendix I.4b. Mechanistic Vegetation Model

ii) Extent: Okanagan-Kettle Region



Appendix I.4b. Mechanistic Vegetation Model

iii) Extent: Washington-British Columbia Transboundary Region



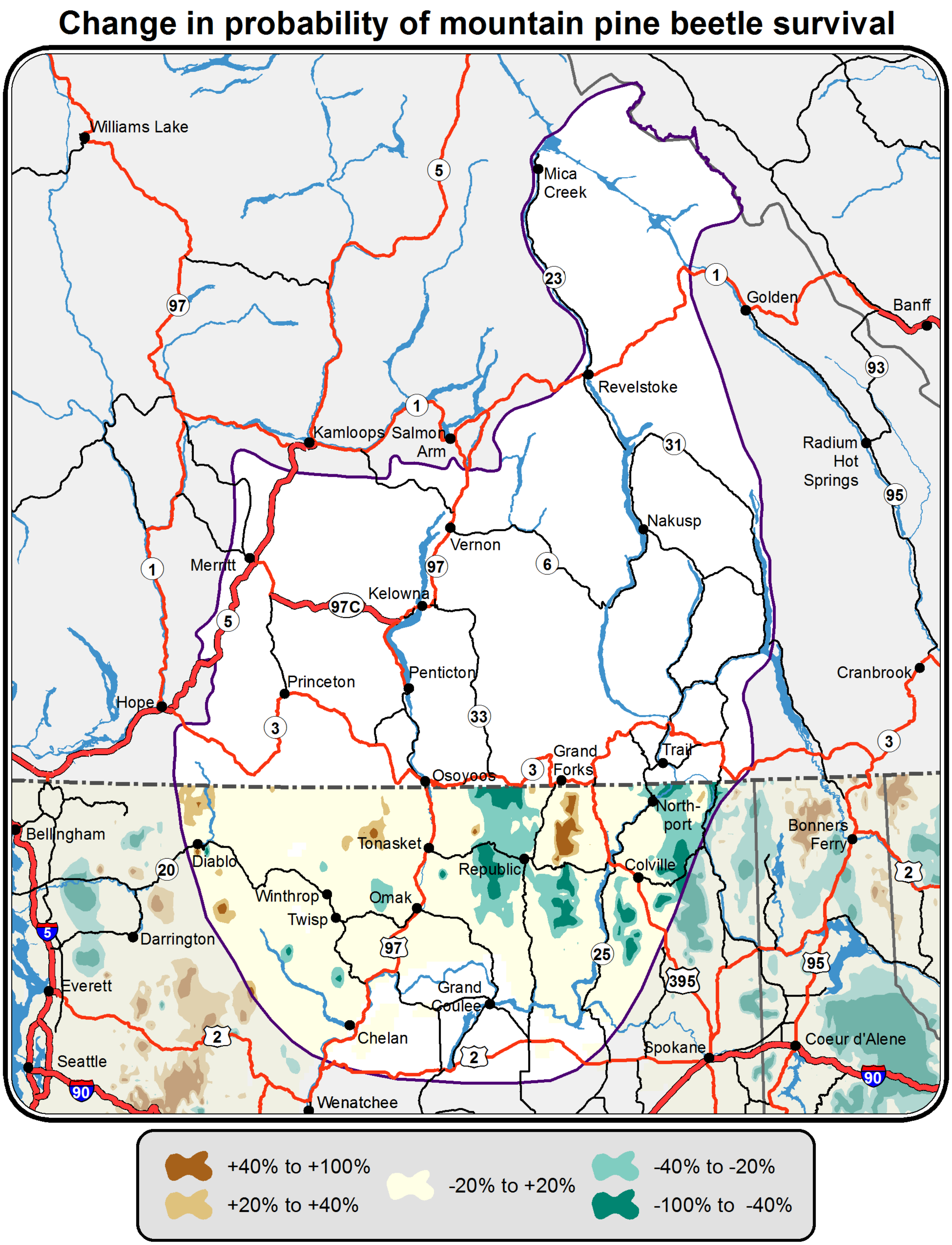
Appendix I.5. Projected Changes in Probability of Mountain Pine Beetle Survival

Projected changes in the probability of climatic suitability for mountain pine beetles for the period 2001 to 2030 (relative to 1961 to 1990), where brown indicates areas where pine beetles are projected to increase in the future and green indicates areas where pine beetles are projected to decrease in the future.[xiv,xv]

[xiv] Mote, P.W., Snover, A.K., Capalbo, S.M., Eigenbrode, S., Glick, P., Littell, J.S., Raymondi, R., Reeder, S. 2014. Chapter 21 in *Climate Change Impacts in the United States: The Third U.S. National Climate Assessment*, J. Melillo, Terese (T.C.) Richmond, and G.W. Yohe, Eds., U.S. Global Change Research Program, 16-1-nn.
[xv] Changes in probability of survival are based on climate-dependent factors important in beetle population success, including cold tolerance, spring precipitation, and seasonal heat accumulation.[xiv] Projections are only available for the United States.

Appendix I.5. Probability of Mountain Pine Beetle Survival

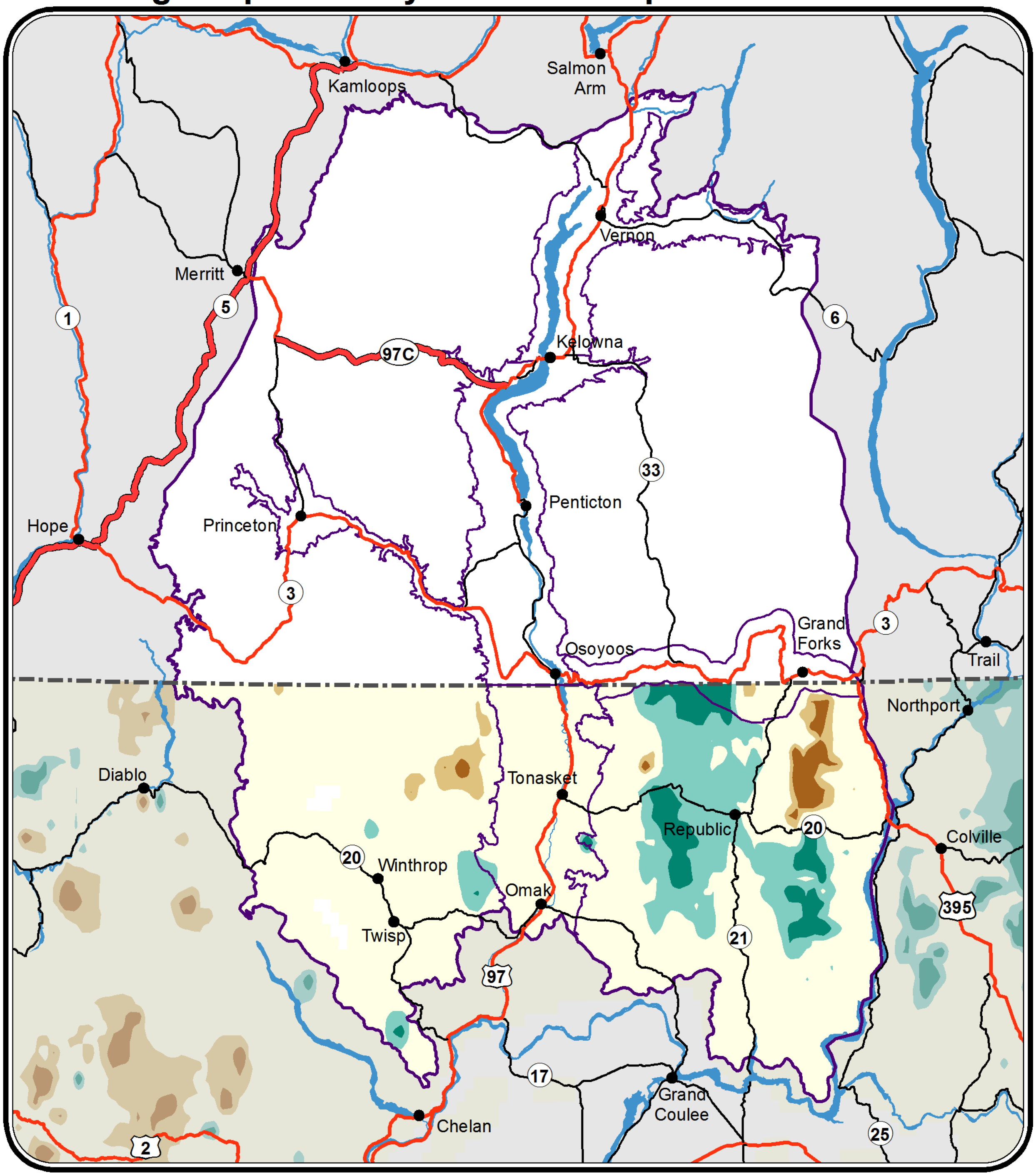
i) Extent: Okanagan Nation Territory



Appendix I.5. Probability of Mountain Pine Beetle Survival

ii) Extent: Okanagan-Kettle Region

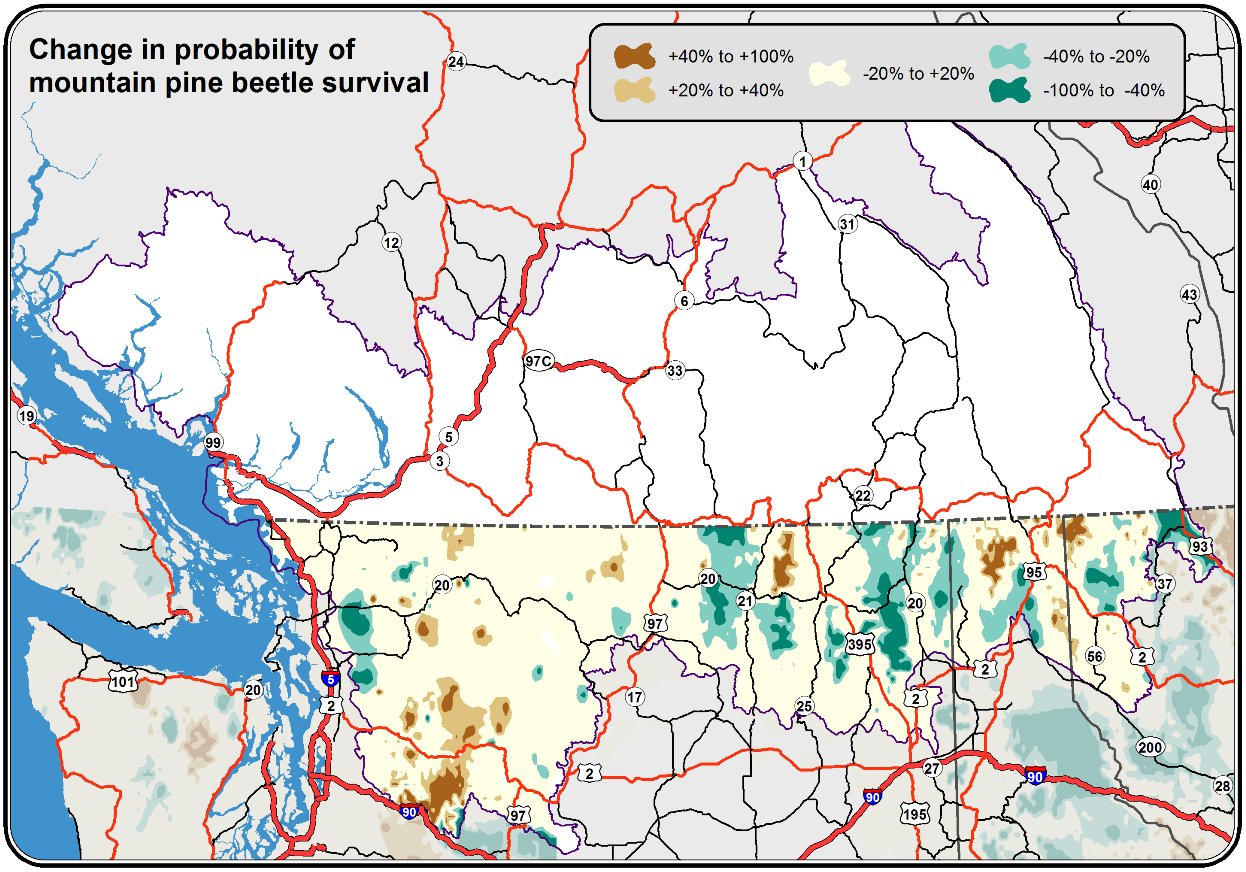
Change in probability of mountain pine beetle survival



+40% to +100%
+20% to +40%
-20% to +20%
-40% to -20%
-100% to -40%

Appendix I.5. Probability of Mountain Pine Beetle Survival

iii) Extent: Washington-British Columbia Transboundary Region



Appendix I.6. Projected Changes in Relevant Climate Variables

The following projections of future climate were identified by project partners as being most relevant to understanding and addressing climate impacts on Lewis's woodpecker connectivity.[xvi] Future climate projections were gathered from two sources, except where otherwise noted: 1) the Integrated Scenarios of the Pacific Northwest Environment,[9] which is limited to the extent of the Columbia Basin; and the Pacific Climate Impacts Consortium's Regional Analysis Tool,[10] which spans the full transboundary region. For many climatic variables, noticeable differences in the magnitude of future changes can be seen at the US-Canada border; this artifact results from differences on either side of the border in the number of weather stations, the way temperature and precipitation were measured, and differences in the approach used to process these data to produce gridded estimates of daily weather variations.

a) **Spring (April 1st) Snowpack.** This map snows the percent change in snow water equivalent (SWE) on April 1st. April 1st is the approximate current timing of peak annual snowpack in Northwest mountains. SWE is a measure of the total amount of water contained in the snowpack. Projected decreases in SWE are depicted by the yellow to red shading.

b) **Days with High Fire Risk** (Energy Release Component, ERC > 95th percentile).[xvii] This map shows the projected change in the number of days when the ERC – a commonly used metric to project the potential and risk of wildfire – is greater than the historical 95th percentile among all daily values.

c) **Potential Evapotranspiration, July-September.** This map shows the percent change in potential evapotranspiration (the amount of evaporation that would occur if a sufficient water source were available) between July and September. Projected changes in potential summer evapotranspiration are depicted by the teal to brown shading.

d) **Dry Spell Duration.** This map shows the projected change, in percent, in the maximum number of consecutive days with less than 1 mm of precipitation. Projected change in dry spell duration is depicted by the brown to green shading.

e) **Total Spring Precipitation, March-May.** This map shows the projected change, in percent, in total spring (March-May) precipitation. Projected changes in total spring precipitation are depicted by the yellow to green shading.

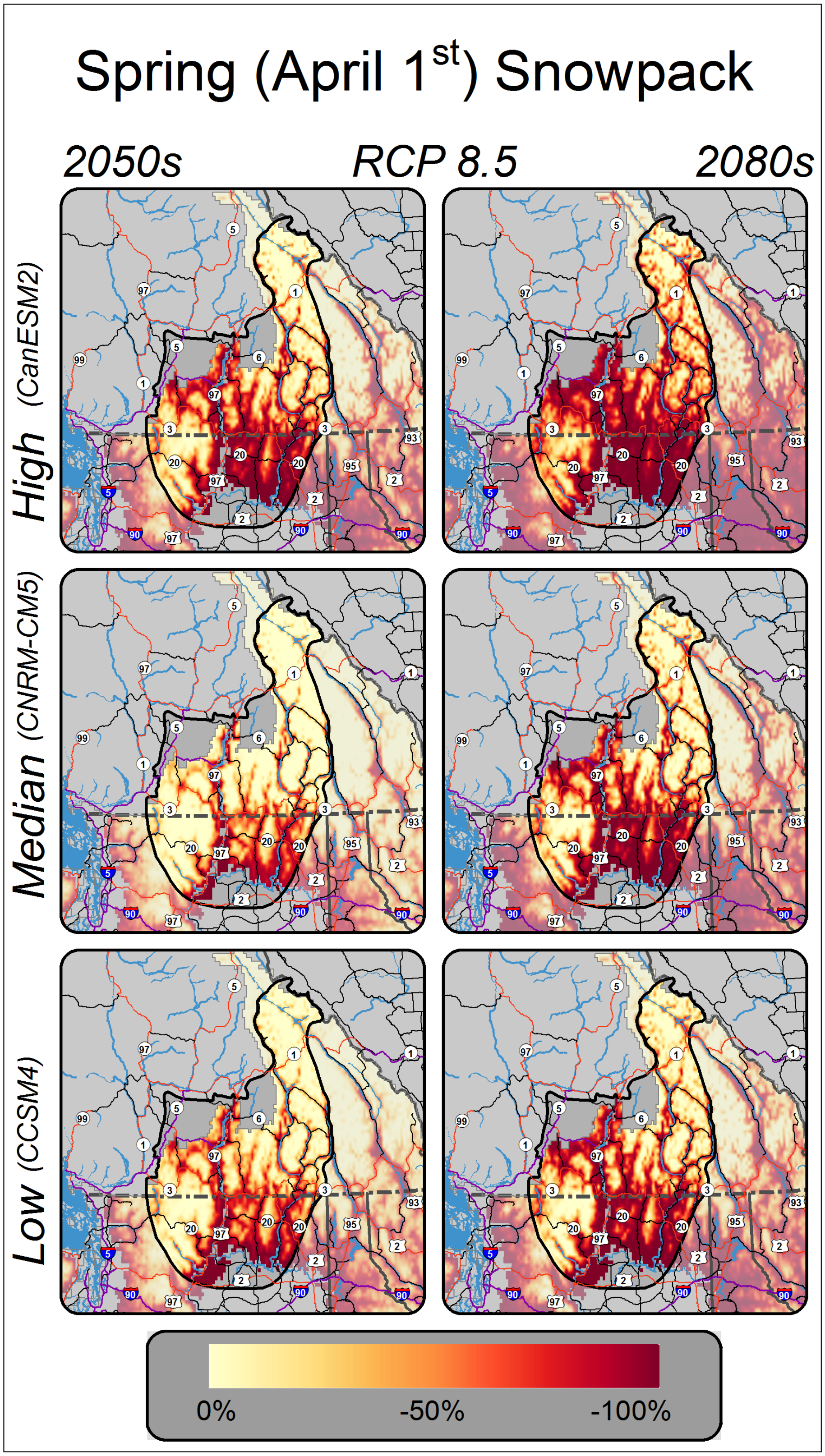
f) **Soil Moisture, July-September.** This map shows the projected change, in percent, in summer soil moisture. Projected changes in soil moisture are depicted by the brown to green shading.

[xvi] All projections but "Days with High Fire Risk" are evaluated for the 2050s (2040-2069) and the 2080s (2070-2099), based on 3 global climate models (a high (CanESM2), median (CNRM-CM5), and low (CCSM4)), under a high greenhouse gas scenario (RCP 8.5). "Days with High Fire Risk" is evaluated for the 2050s, based on 3 global climate models (a high (CanESM2), median (CNRM-CM5), and low (MIROC5)) using the RCP 8.5 (high) emissions scenario.

[xvii] Abatzoglou, J.T. 2013. Development of gridded surface meteorological data for ecological applications and modeling. *International Journal of Climatology*, 33(1): 121-131.

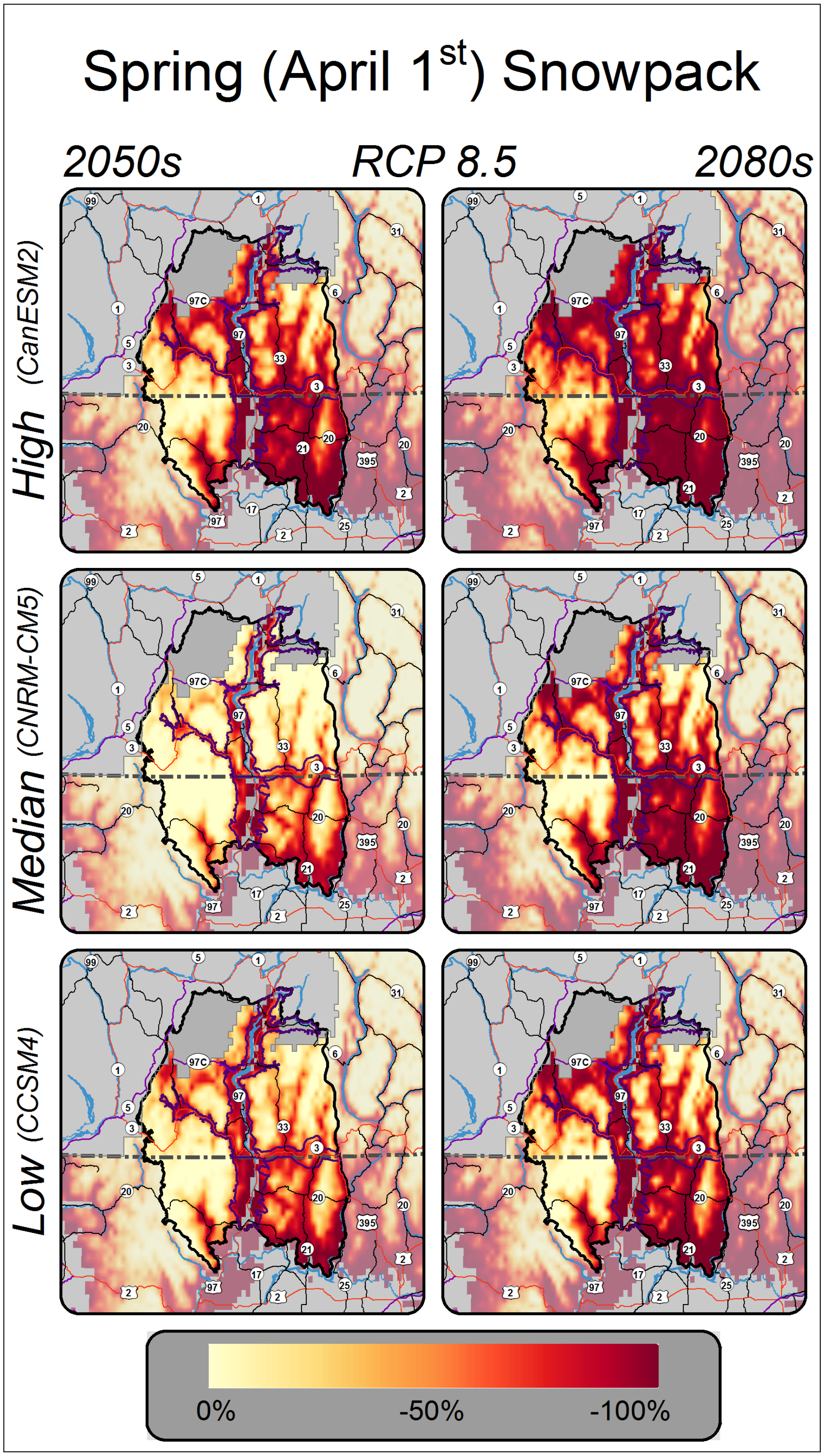
Appendix I.6a. Spring (April 1st) Snowpack

i) Extent: Okanagan Nation Territory



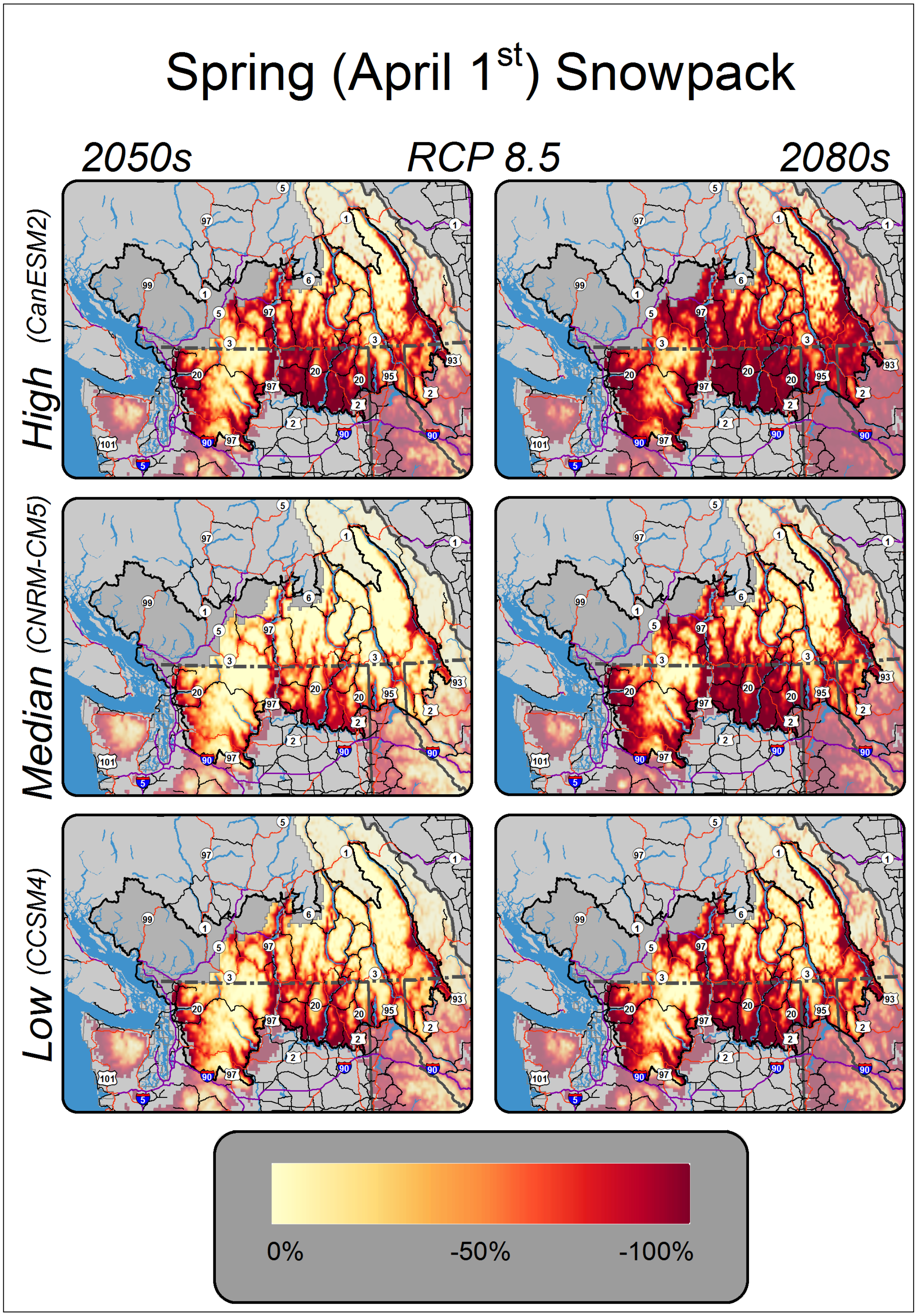
Appendix I.6a. Spring (April 1st) Snowpack

ii) Extent: Okanagan-Kettle Region



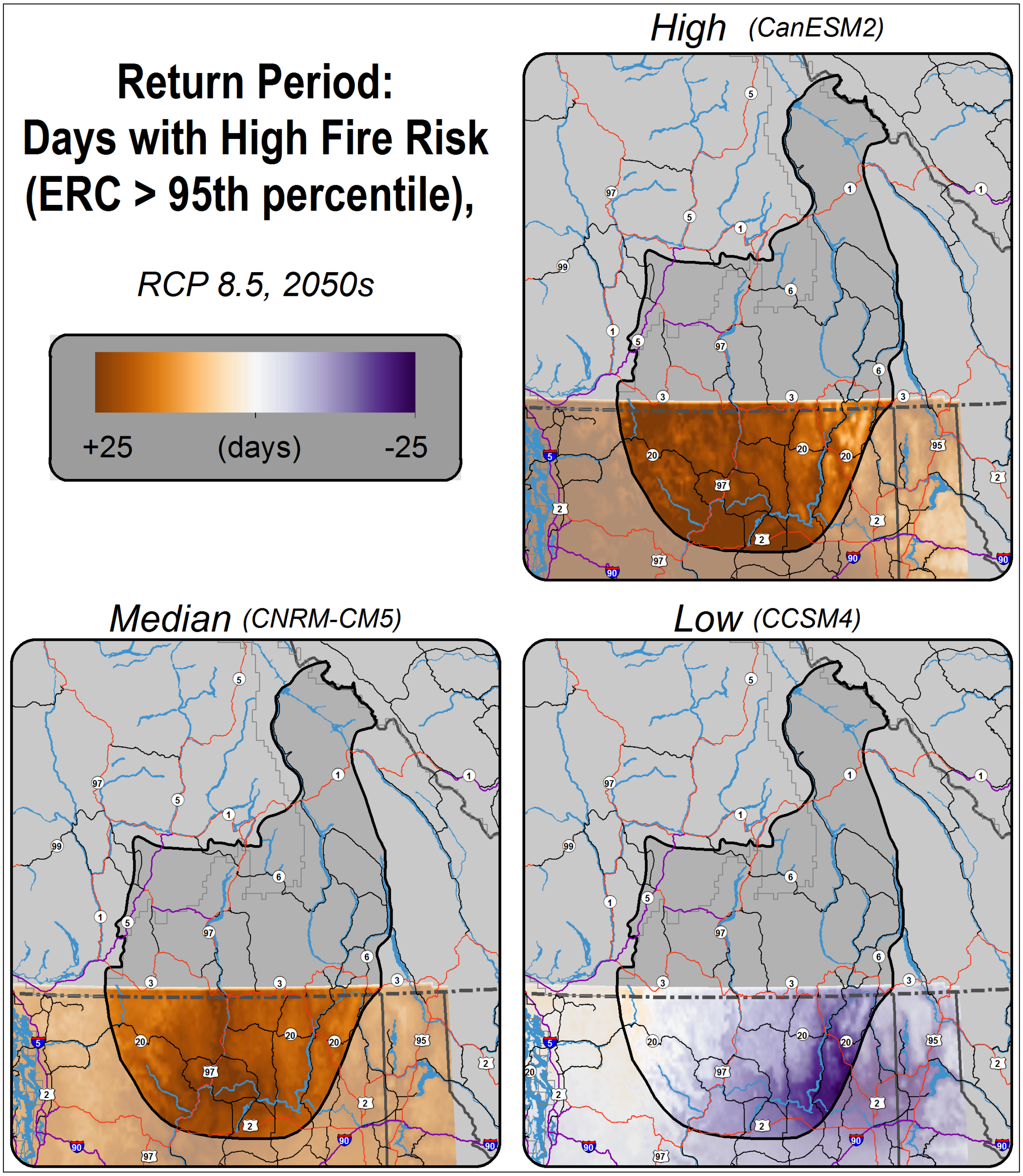
Appendix I.6a. Spring (April 1st) Snowpack

iii) Extent: Washington-British Columbia Transboundary Region



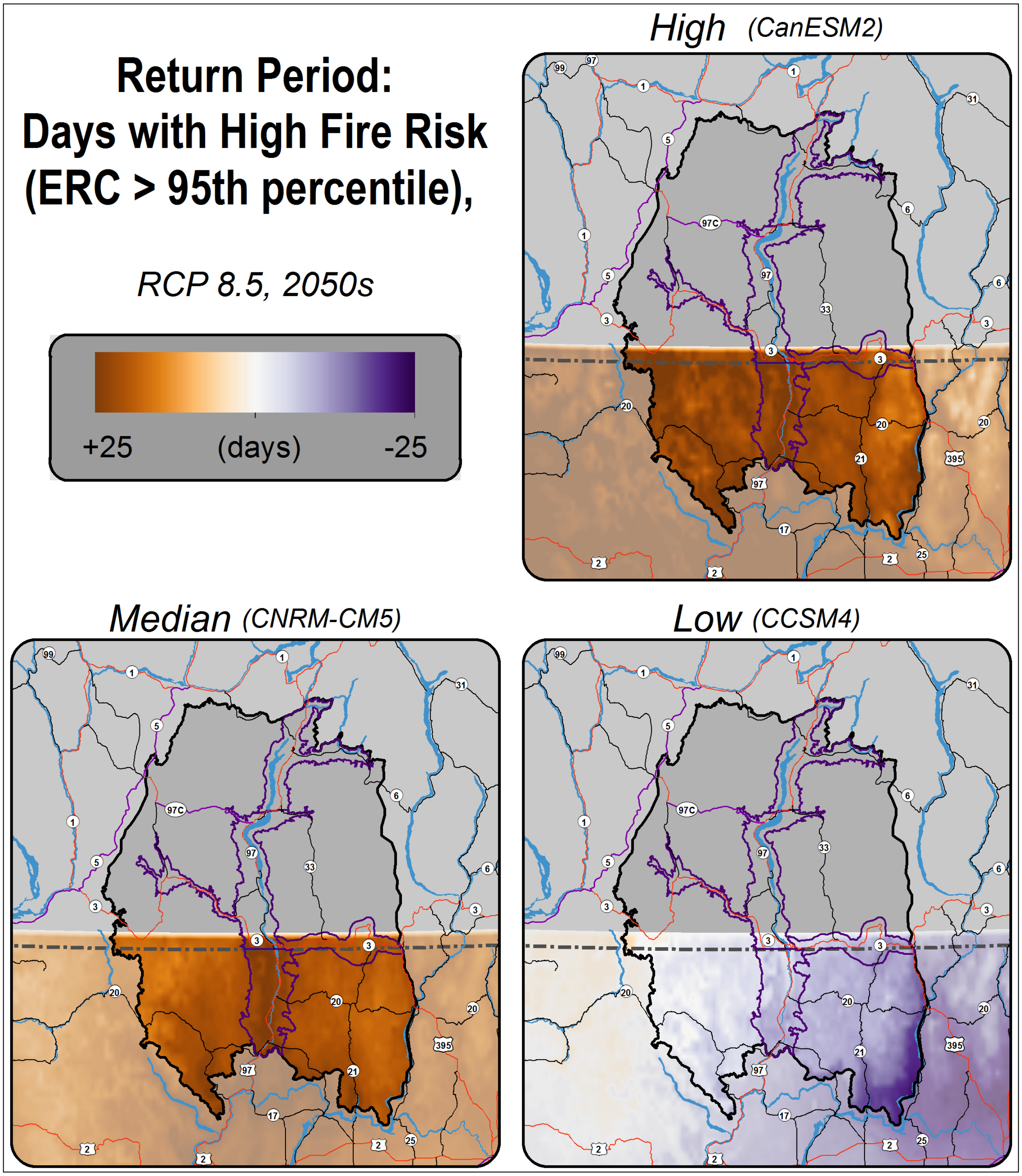
Appendix I.6b. Days with High Fire Risk

i) Extent: Okanagan Nation Territory



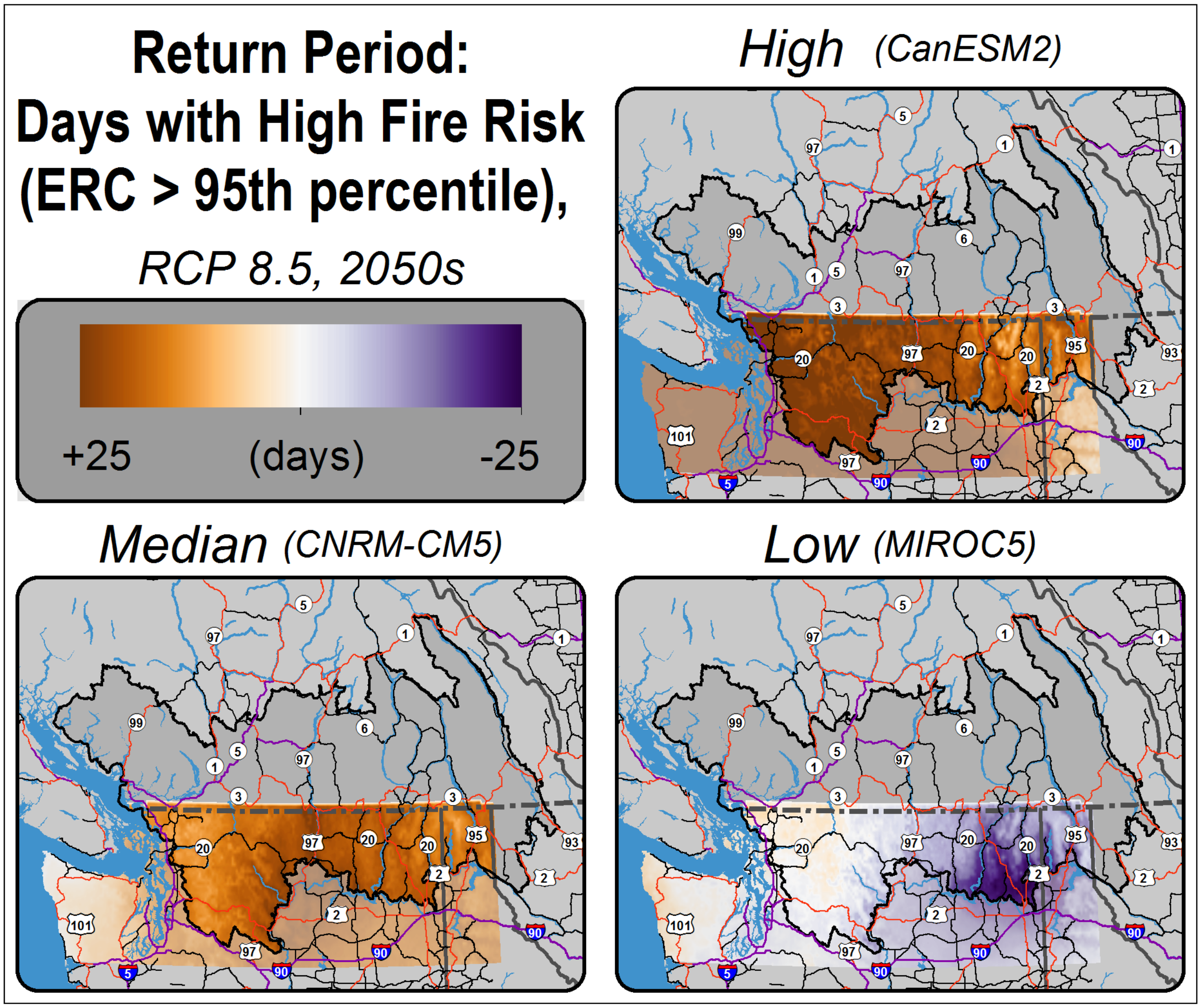
Appendix I.6b. Days with High Fire Risk

ii) Extent: Okanagan-Kettle Region



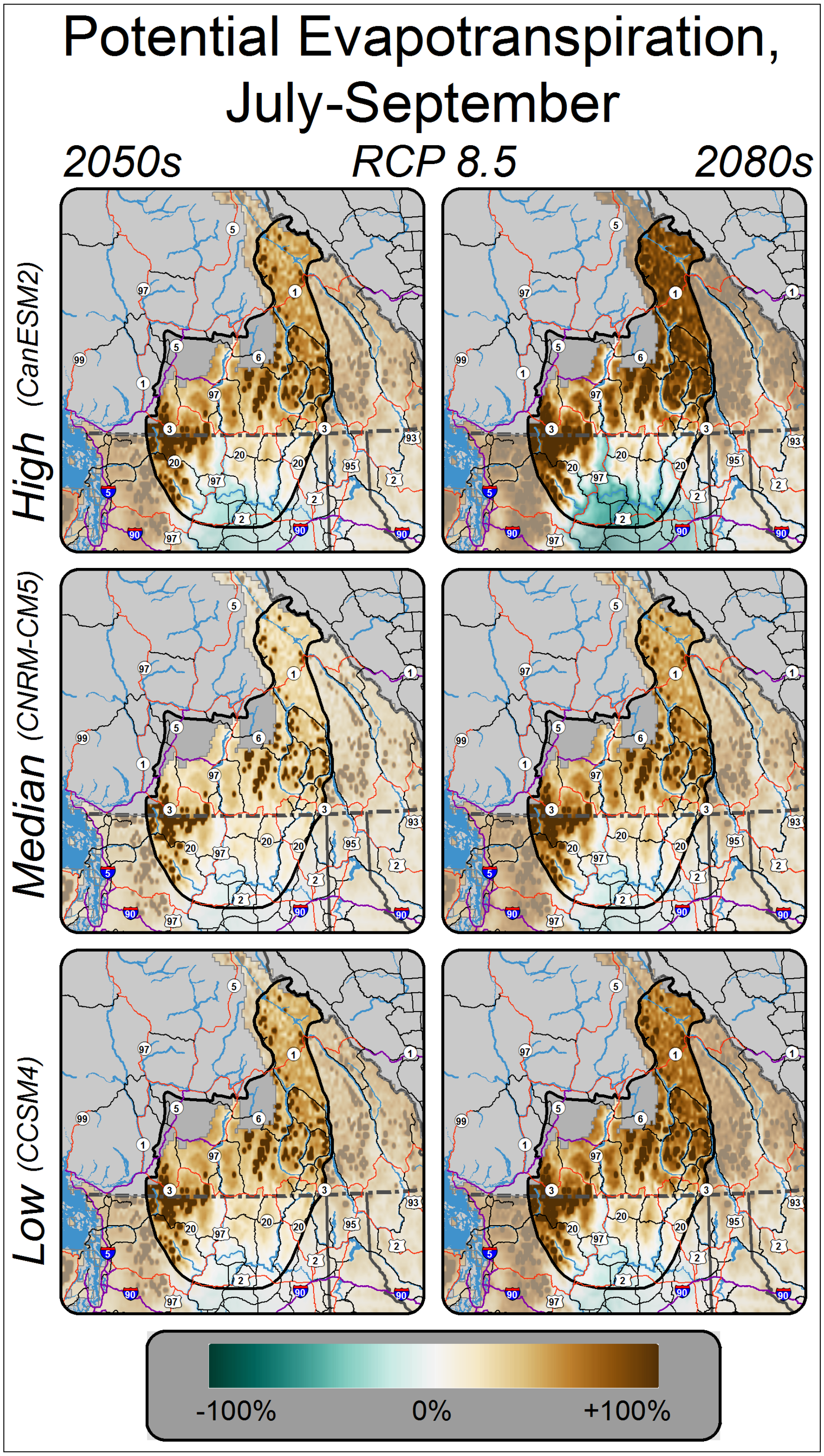
Appendix I.6b. Days with High Fire Risk

iii) Extent: Washington-British Columbia Tranaboundary Region



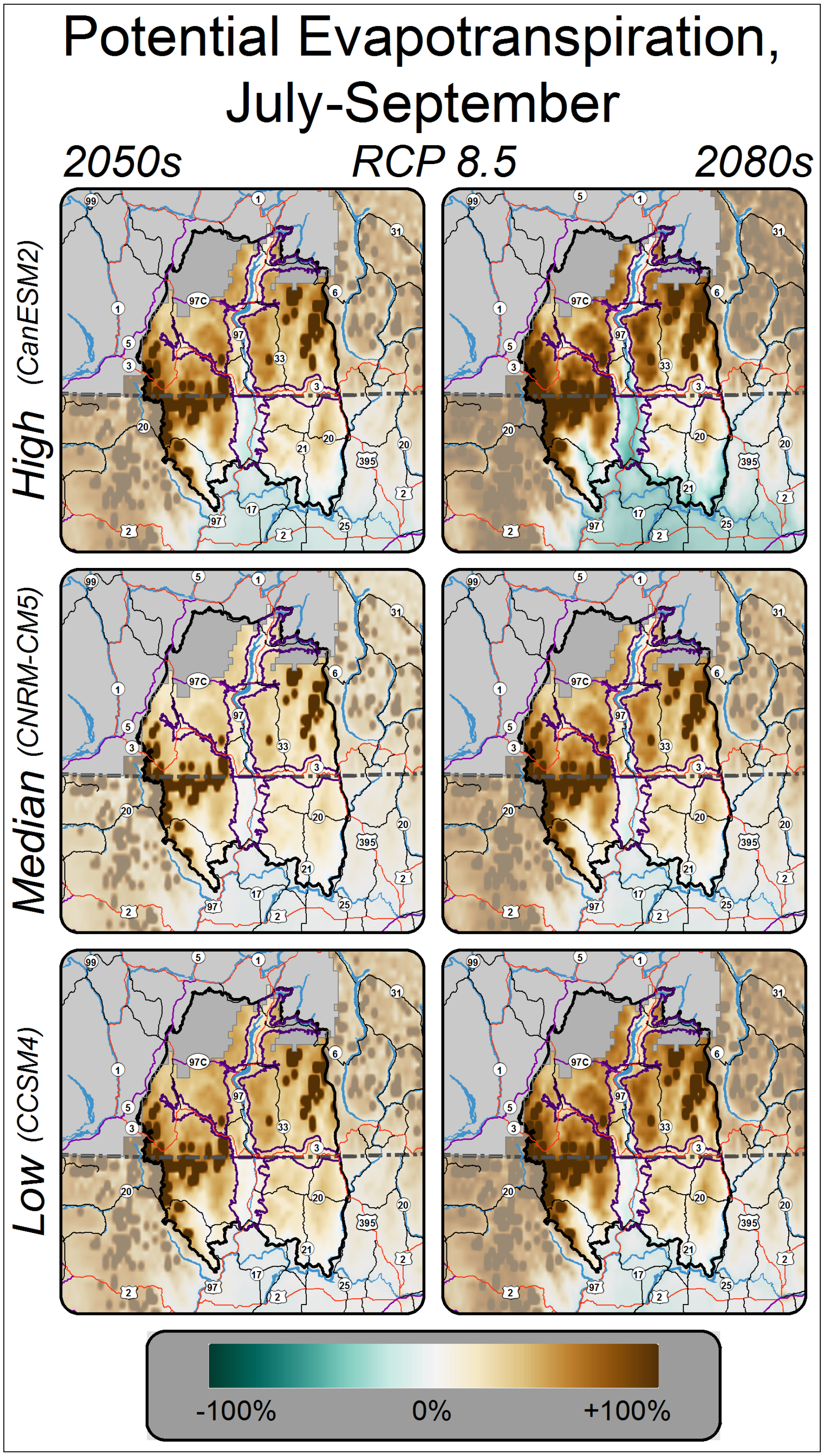
Appendix I.6c. Potential Evapotranspiration, July-September

i) Extent: Okanagan Nation Territory



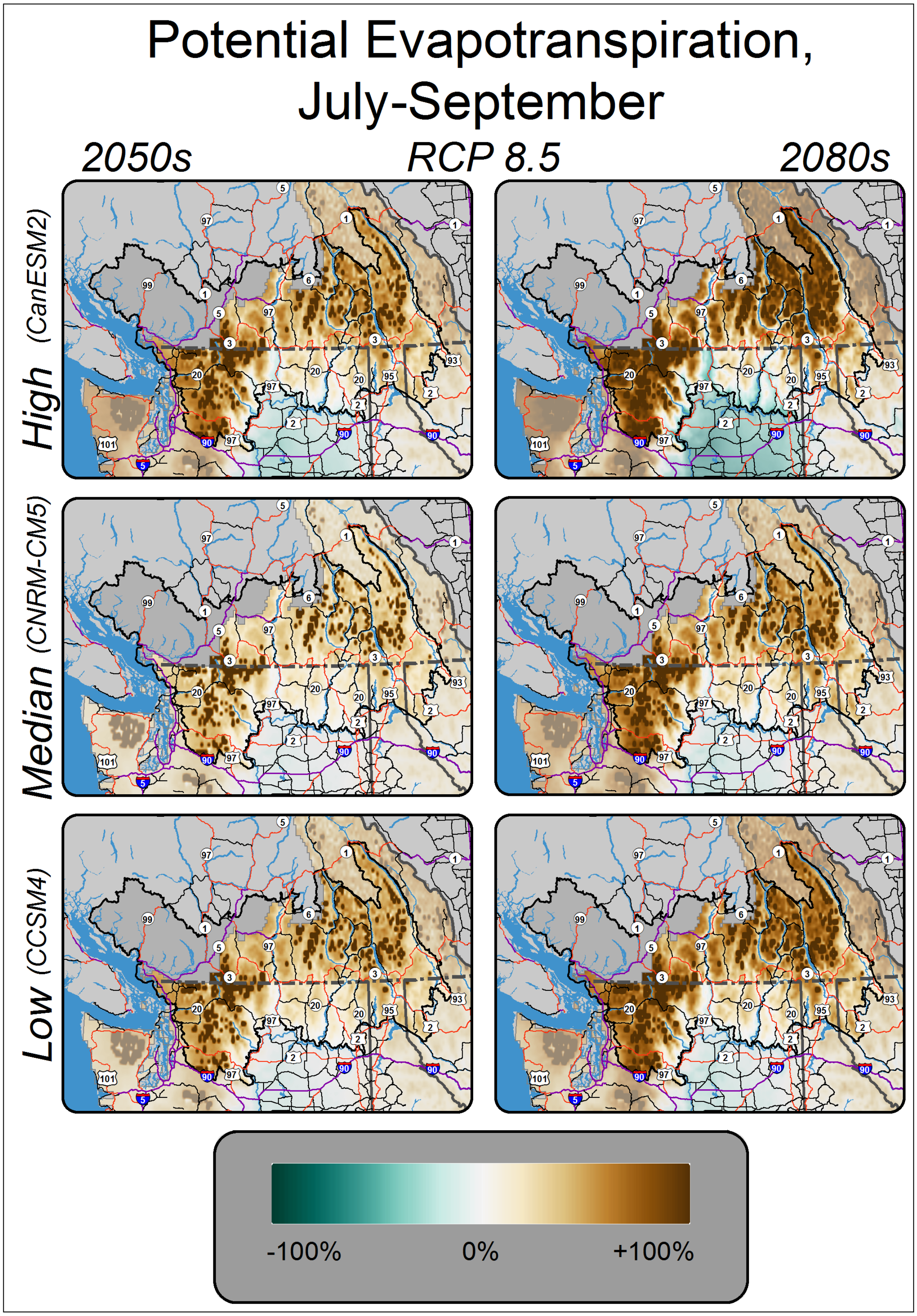
Appendix I.6c. Potential Evapotranspiration, July-September

ii) Extent: Okanagan-Kettle Region



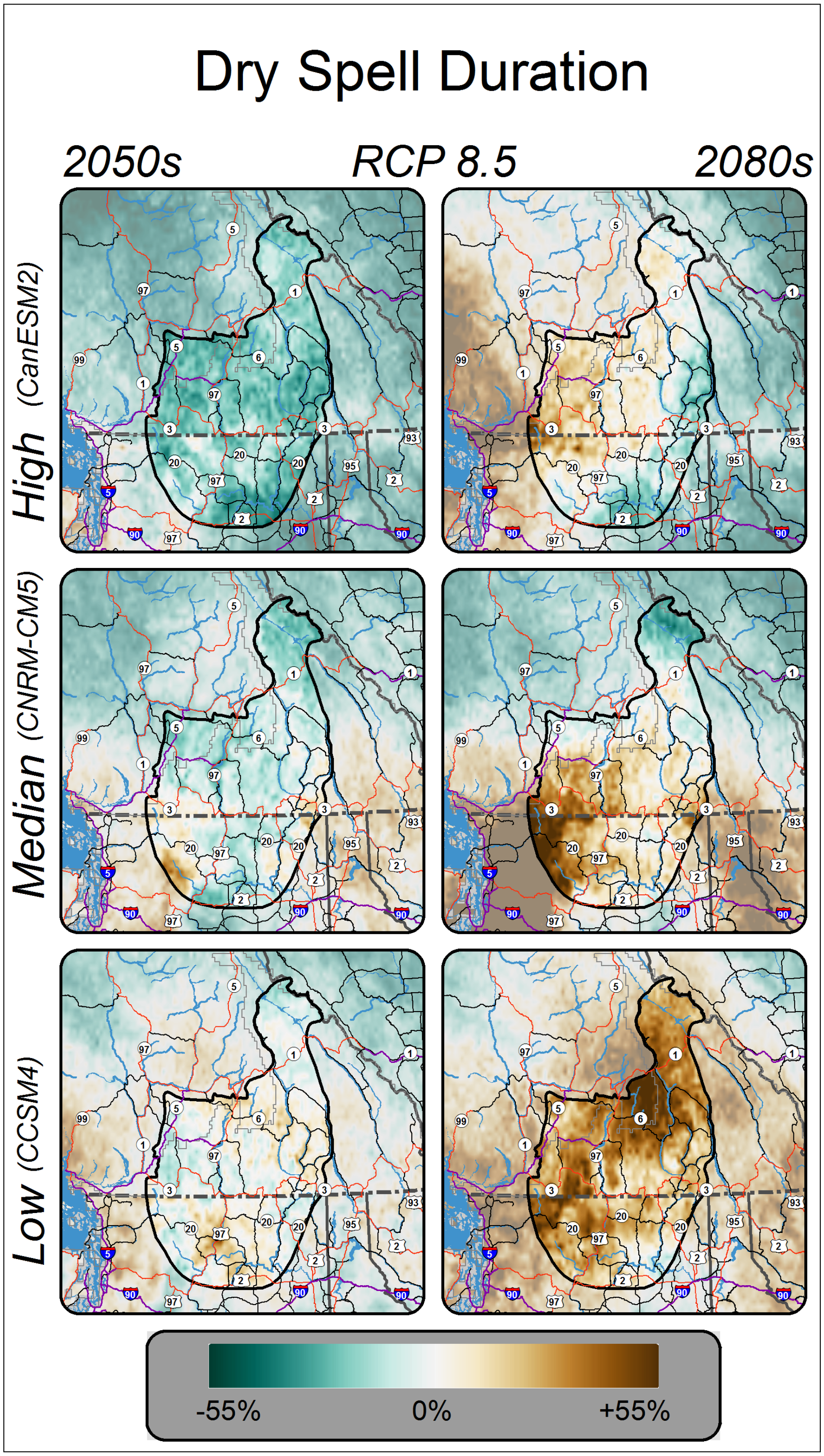
Appendix I.6c. Potential Evapotranspiration, July-September

iii) Extent: Washington-British Columbia Transboundary Region



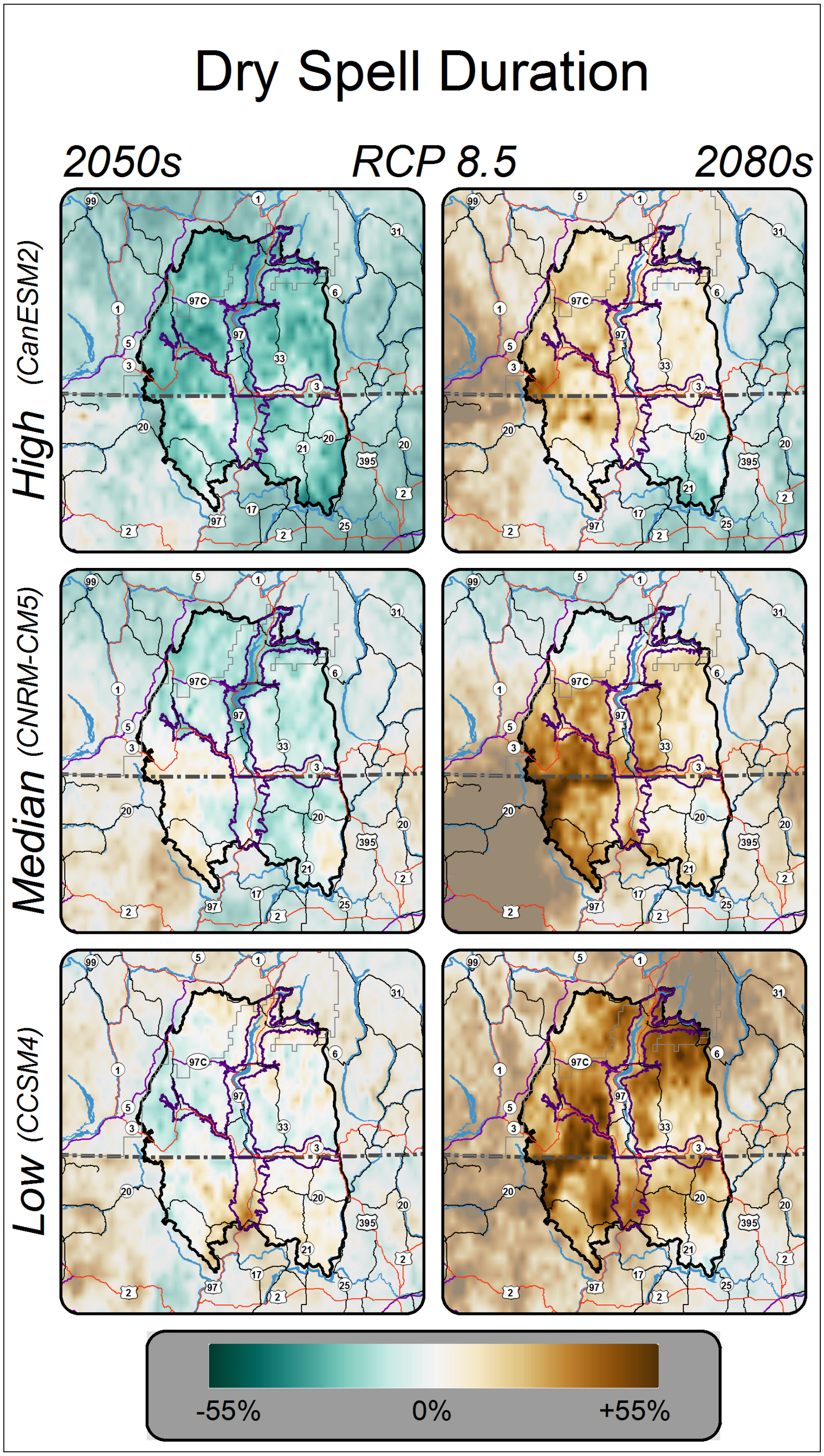
Appendix I.6d. Dry Spell Duration

i) Extent: Okanagan Nation Territory



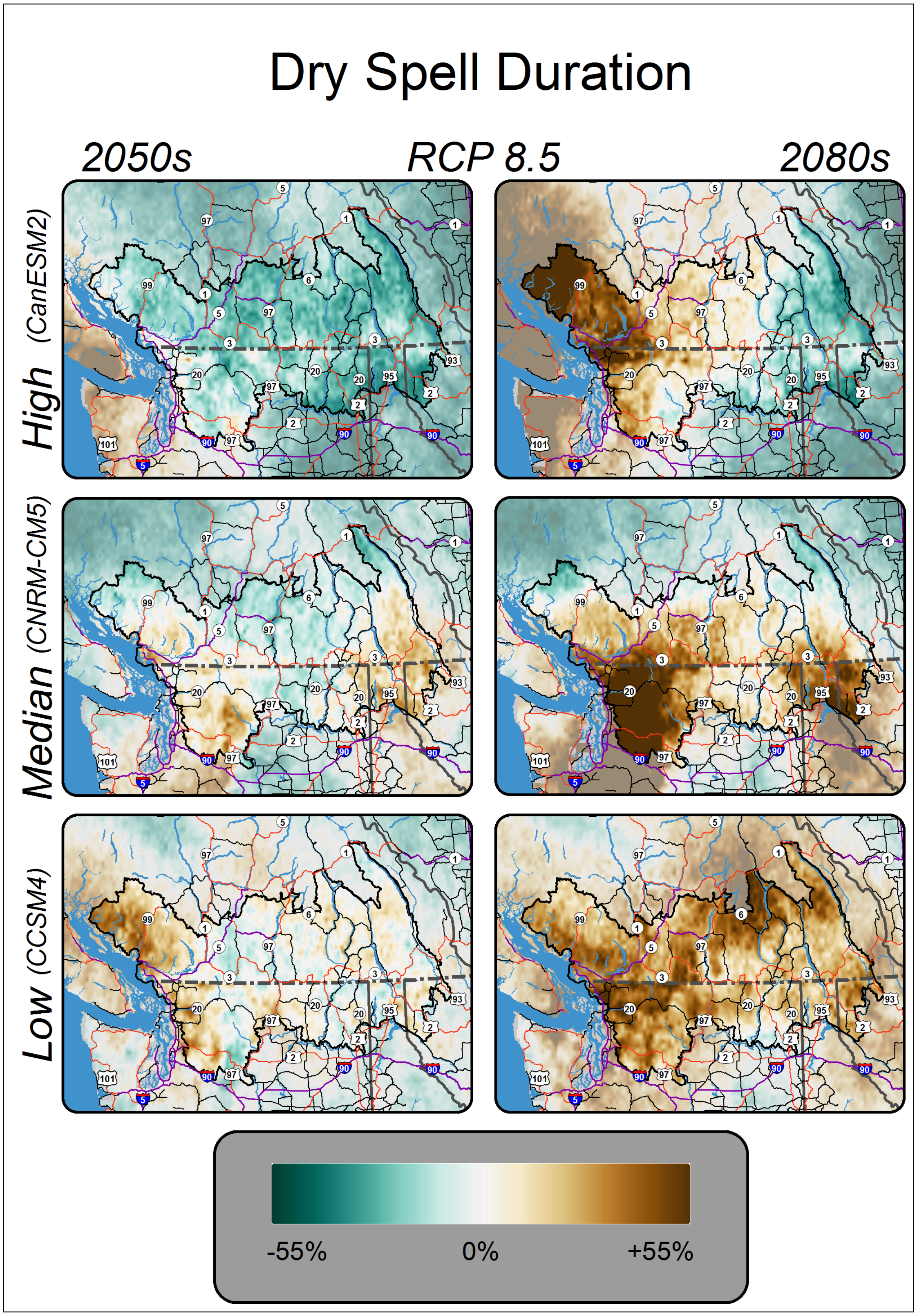
Appendix I.6d. Dry Spell Duration

ii) Extent: Okanagan-Kettle Region



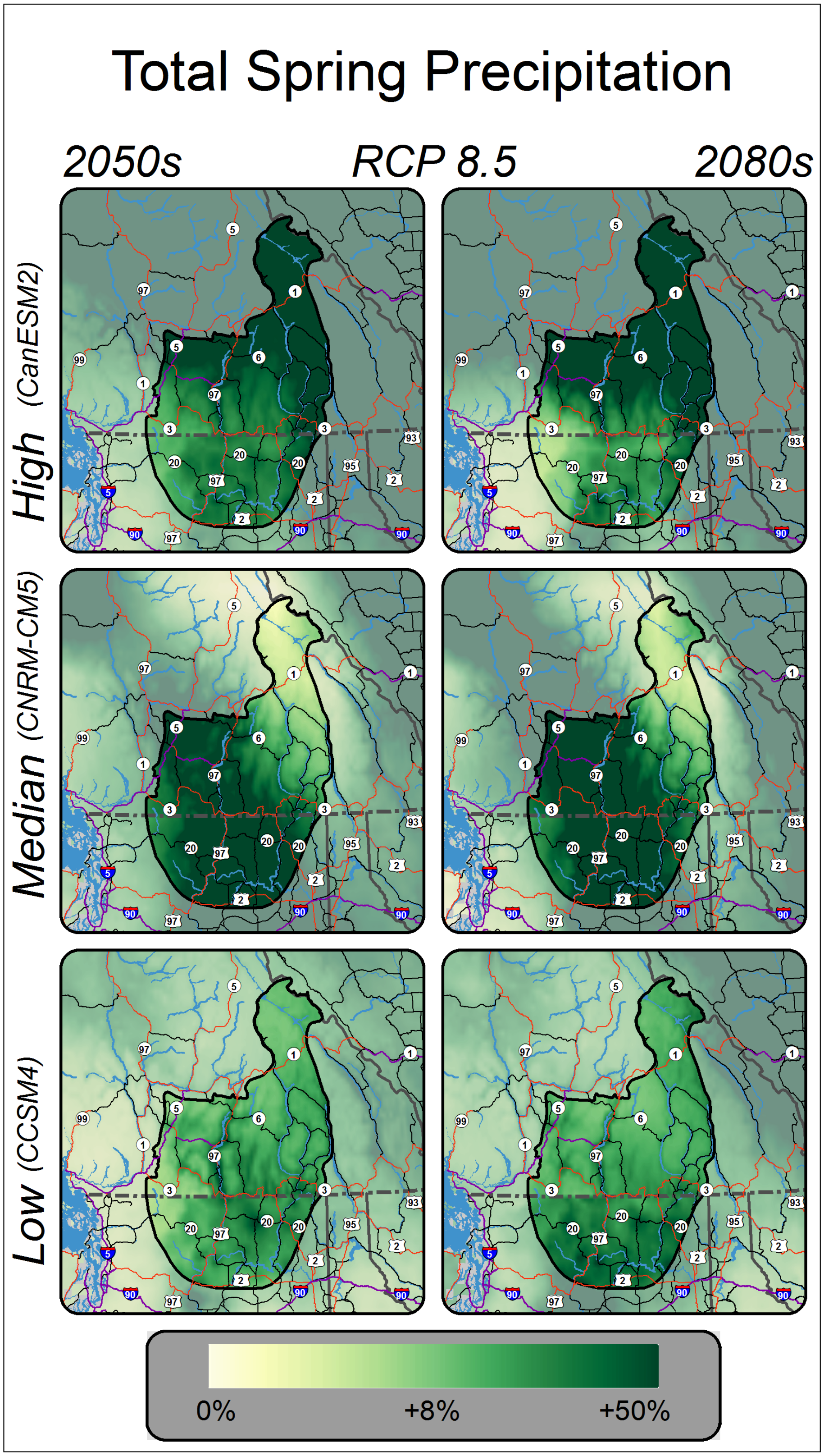
Appendix I.6d. Dry Spell Duration

iii) Extent: Washington-British Columbia Transboundary Region



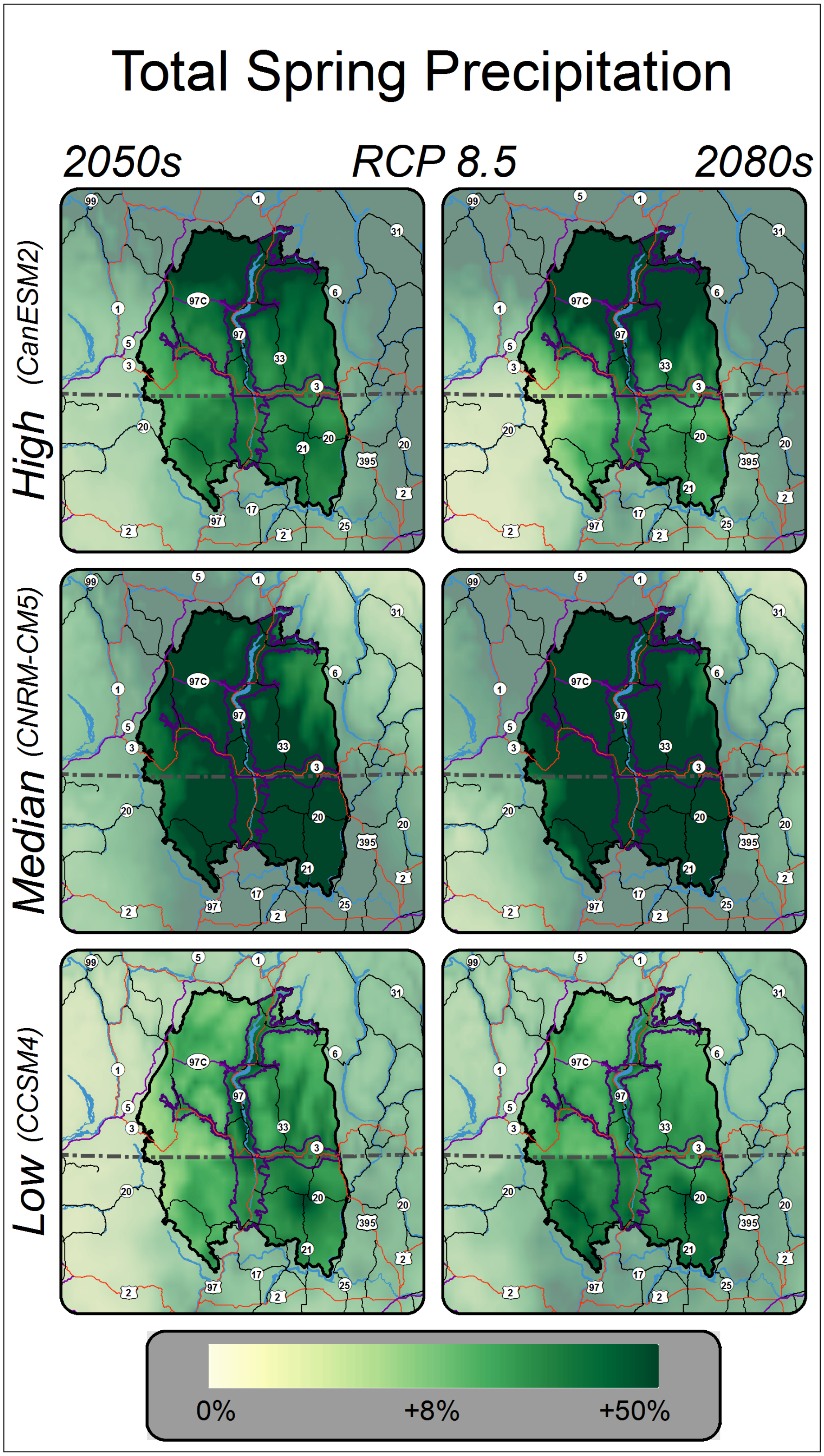
Appendix I.6e. Total Spring Precipitation, March-May

i) Extent: Okanagan Nation Territory



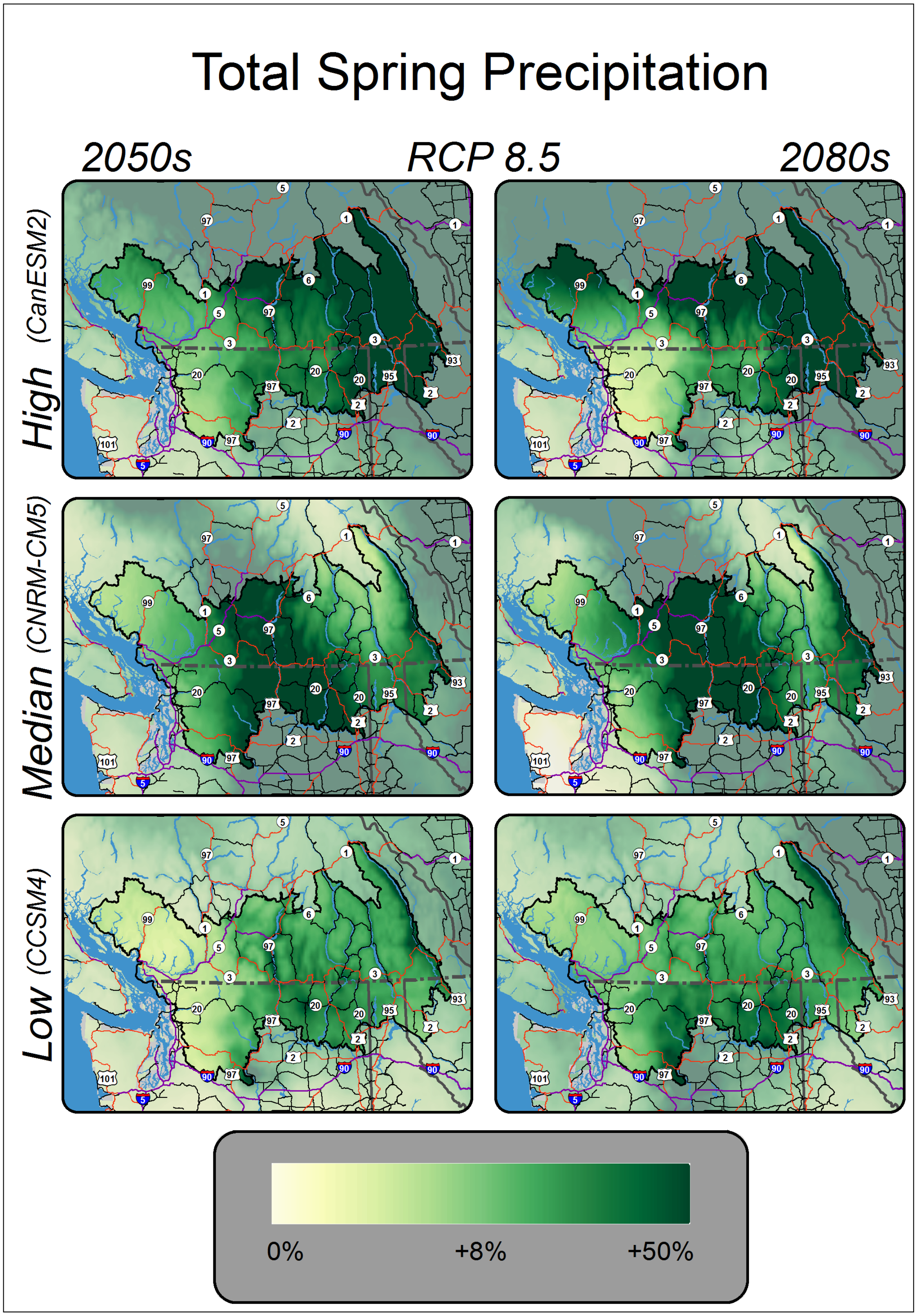
Appendix I.6e. Total Spring Precipitation, March-May

ii) Extent: Okanagan-Kettle Region



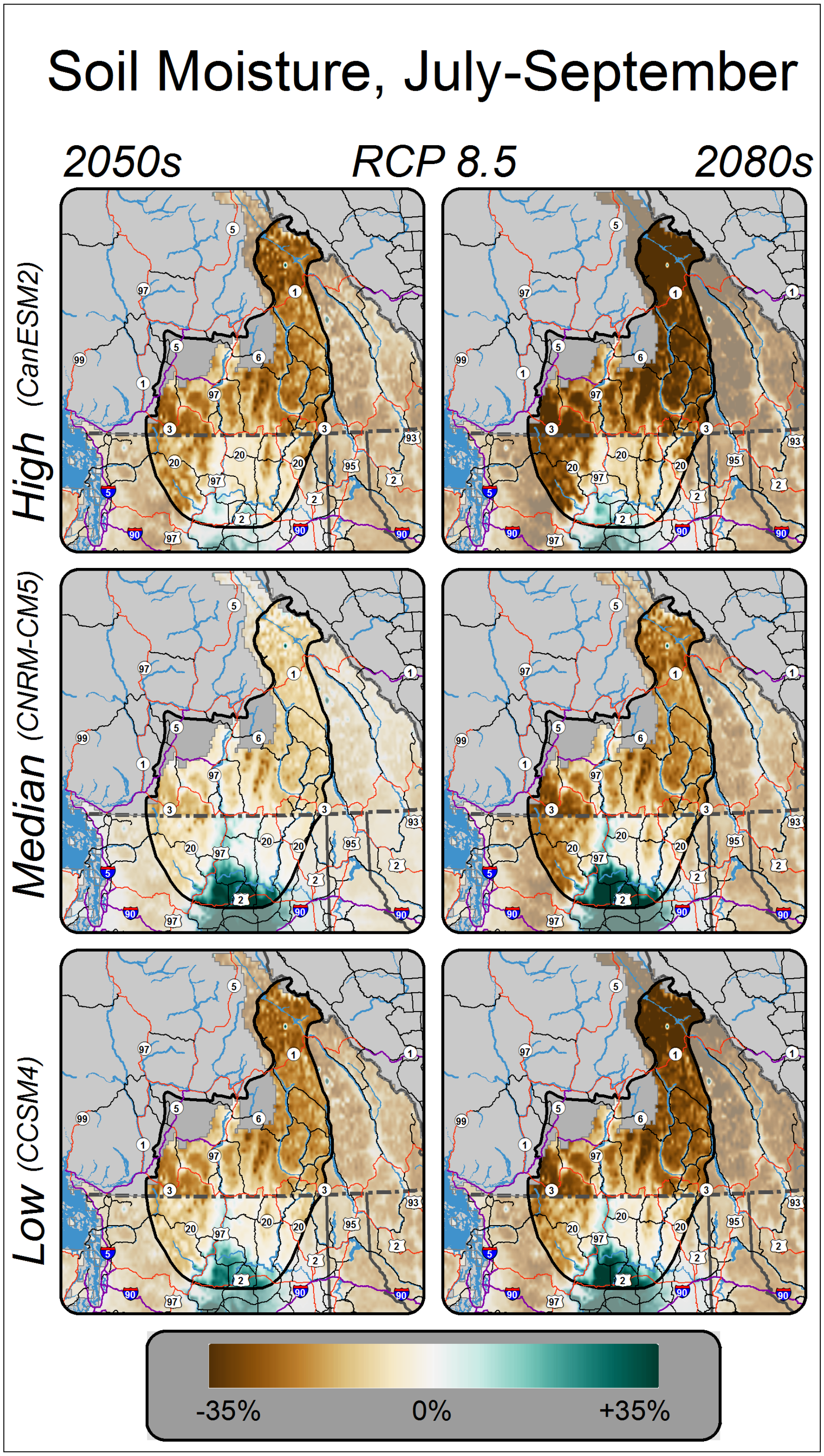
Appendix I.6e. Total Spring Precipitation, March-May

iii) Extent: Washington-British Columbia Transboundary Region



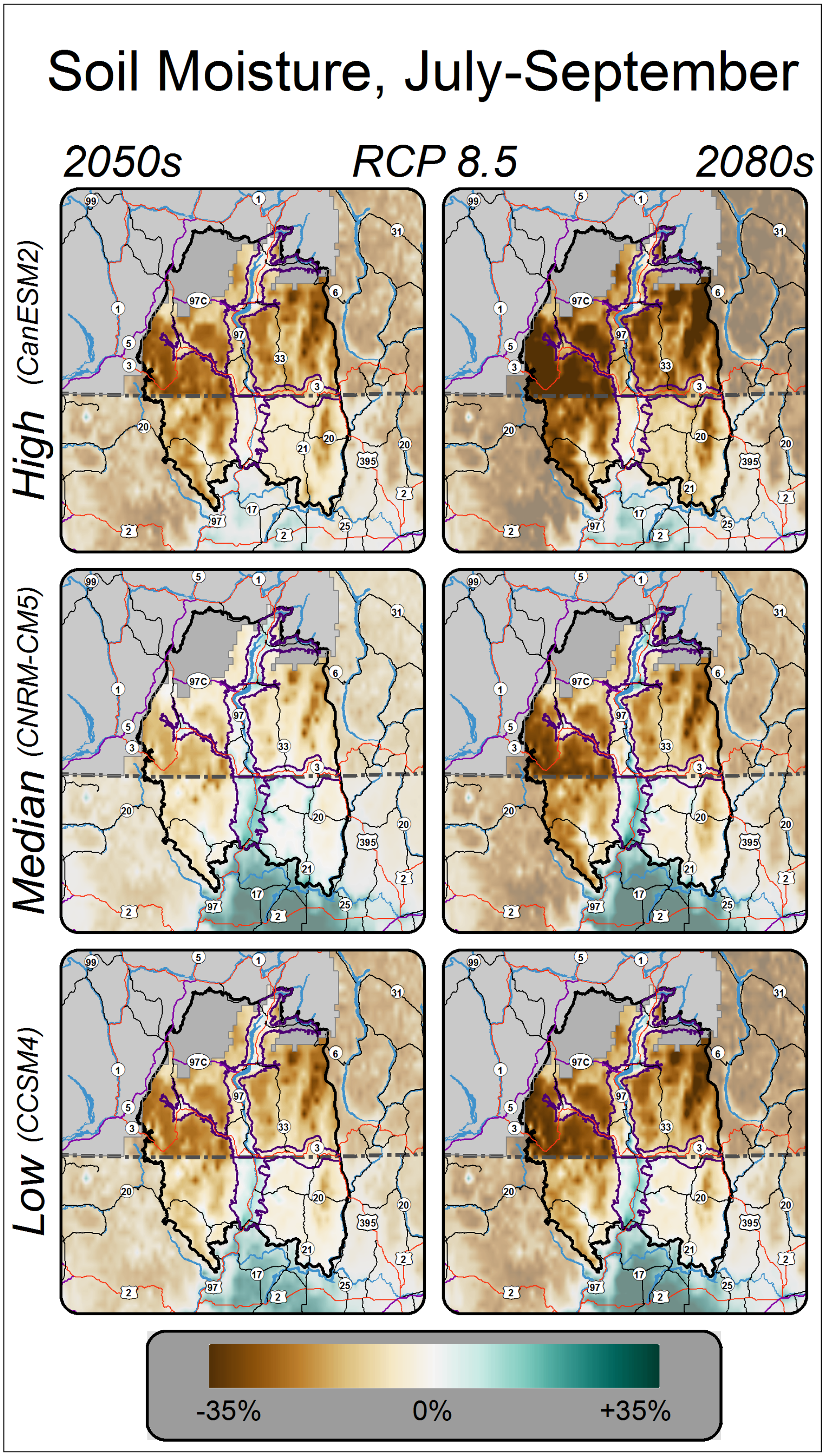
Appendix I.6f. Summer Soil Moisture, July-September

i) Extent: Okanagan Nation Territory



Appendix I.6f. Soil Moisture, July-September

ii) Extent: Okanagan-Kettle Region



Appendix I.6f. Soil Moisture, July-September

iii) Extent: Washington-British Columbia Transboundary Region